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ORIGINAL ARTICLES.

I.—Some Additions to the Australian Tertiary Echinoidea.

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(PLATES XIII. and XIV.)

THE Tertiary Echinoid fauna from the South-east of Australia is well known from the work of Duncan,[1] Laube,[2] R. Etheridge, jun.,[3] and M'Coy.[4] A collection made by H. P. Woodward, Esq., F.G.S., from the Tertiary beds of Willunga near Adelaide, enables several additions to be made. These are of interest as they considerably strengthen the Cretaceous facies which the fauna owes to the presence of such genera as *Holaster* and *Micraster*, and as they throw some additional light upon a genus the stability of which has long been questioned. The collection has been presented to the British Museum (Nat. Hist.) by H. Y. L. Brown, Esq., F.G.S., the Government Geologist for South Australia.

Dr. J. E. Taylor, during a visit to the cliffs of the Murray River at Morgan, South Australia, made a collection of fossils which is now in the Ipswich Museum. This includes two new species of Echinoids, and a description of these may be conveniently included in the present paper. For the loan of the specimens I must express my thanks to Dr. Taylor.

I.—Mr. H. P. Woodward's Collection, from Willunga.

Fam. Cidaridæ.

Gen. *Cidaris*, Leske, 1778.

Cidaris (*Leiocidaris*) sp. Duncan, Q.J.G.S. xliii. p. 412 (B.M. E 197), 1887.

There is a fragment (B.M. E 3377) of a *Cidaris* which, as it contains ambulacral and interambulacral plates, admits of identifica-

[1] P. M. Duncan, "A Description of some Fossil Corals and Echinoderms from the South Australian Tertiaries," Ann. Mag. Nat. Hist. (3) vol. xiv. pp. 161–8, pls. v. and vi. "On the Echinodermata of the Australian Cainozoic (Tertiary) Deposits," Q.J.G.S. xxxiii. 1877, pp. 42–73, pl. iii. and iv. "A Revision of the Echinoidea from the Australian Tertiaries," Q.J.G.S. xliii. 1887, pp. 411–430.

[2] G. C. Laube, "Ueber einige fossile Echiniden von den Murray Cliffs in Süd-Australien," Sitz. k. Ak. Wiss. Wien. lix. Abth. i. 1869, pp. 183–98.

[3] R. Etheridge, jun., "Description of a New Species of the Genus *Hemipatagus*, Desor, from Tertiary Rocks of Victoria, Australia; with Notes on some previously described Species from S. Australia," Q.J.G.S. 1875, pp. 444–50, pl. xxi.

[4] F. M'Coy, Prod. Pal. Victoria, dec. vi. 1879, vii. 1882.

tion. Its characters agree with those of the specimen from Bairnsdale described but not named by Dr. Duncan. This species differs from *L. australiæ* mainly by the very deeply impressed areolæ which occur in the latter.

Spines.

The collection includes a considerable number of spines which closely resemble those of *Goniocidaris*, *Phyllacanthus* and possibly also of *Heterocentrotus*. The only plates to which the spines of the *Glyphostomata* might be referred are too inperfect for description (B.M. E 3378–9).

Fam. Cassidulidæ.

Gen. *Cassidulus*, Lam. 1801.

Cassidulus longianus, sp. nov. Pl. XIII. Figs. 1–3.

Outline from above elliptical, somewhat pointed anteriorly. Abactinally it is evenly rounded; the vertex slightly precentral. Actinal surface slightly concave with the mouth in the centre of the depression. A wide median bare band runs backward from the mouth.

Apical system at vertex. Five radial and four basal pores. Madreporite large, occupying whole of centre of the system.

Ambulacra. — Petals sublanceolate; flush; open below; pores yoked. The single pores of the extrapetaloid plates are on the adoral margin. Petals nearly equal: the posterior laterals are slightly narrower and less lanceolate than the anterolateral.

Peristome anterior: at deepest part of the slight actinal depression. Floscelle very prominent. Phyllodes very narrow at oral end, but expanding into wide areas with five pores in the outer row of each side. Bourrelets very prominent. Mouth pentagonal.

Anus long, narrow and oval; situated at upper end of a long narrow groove, which however barely influences the posterior margin.

Dimensions.	Largest specimen.	Type, Fig. 1.	Type, Fig. 2.
Length	65 mm.	45 mm.	43 mm.
Width	56 ,,	42 ,,	40 ,,
Height	30 ,,	22 ,,	20 ,,
Distance of apex from anterior edge ...	27 ,,	19 ,,	...
Distance of mouth ,, ...	26 ,,	...	17 ,,
Maximum width of poriferous zone: antero-lateral ambulacrum ...	2·5 ,,	1·5 ,,	
Maximum width of poriferous zone: postero-lateral ambulacrum ...	2·0 ,,	1·2 ,,	
Length of antero-lateral ambulacrum ...	20 ,,	11 ,,	
Length of postero- ,, ,, ...	22 ,,	12 ,,	

Cassidulus has not previously been described from the Australian Tertiaries. The genus is mainly Cretaceous, but a few species occur in the Eocene. *Cassidulus longianus* is a well-marked species: the bare median band, one of the features of the subgenus *Pygorhynchus*, the long anus and short petals form a series of characters to be met with in no other species of the genus. It most resembles some of the United States Cretaceous forms such as *C. subquadratus*, Conrad.[1]

[1] T. A. Conrad, Journ. Ac. Nat. Sci. Phil. [2] iv. p. 291, pl. xlvii. fig. 19.

Gen. *Echinolampas*, Gray, 1825.

Echinolampas ovulum, Laube.

Sitz. k. Ak. Wiss. Wien. lix. Abth. i. 1869, pp. 191–2.

Laube in 1869 briefly described a specimen from the Murray Cliffs, which he temporarily named *E. ovulum* as it was too imperfect for formal diagnosis. Prof. Duncan subsequently referred a specimen from Bairnsdale (B.M. E 1107) to this species. Laube's type is in the Palæontological Collection of the Hof Museum in Vienna, and owing to the kindness of the Director, Dr. Fuchs, I recently had the opportunity of examining it; there can be no doubt of the correctness of Prof. Duncan's identification. As the species has hitherto been neither figured nor described, this opportunity may as well be taken for doing so: in the following diagnosis both specimens have been used.

Echinolampas ovulum, Laube. Pl. XIII. Figs. 7–8.

Laube, Sitz. k. Ak. Wiss. Wien. Bd. lix. Abth. i. 1869, pp. 191-2.
Duncan, Q.J.G.S. 1877, xxxiii. p. 66; 1887, xliii. p. 420.

Outline seen from below an elongated pentagon with rounded angles; sides tumid, rounding off into the concave actinal surface: tapering posteriorly to a slight rostrum, at the end of which is the anus: well rounded in front.

In elevation it is high, with the vertex behind the apical disc.

Vertex blunt, at the posterior third of the test.

Apical system anterior: details unknown.

Ambulacra with lanceolate petals, open below. The posterior pair the larger. Pores yoked. The petals extend more than two-thirds to the ambitus. In the posterior ambulacra the pore areas are equal (as in *Palæolampas*); in the anterior unequal (as in *Echinolampas*).

Peristome: mouth rounded pentagonal: broader than long: slightly anterior: at deepest part of the actual concavity.

Floscelle rudimentary, formed by slight bourrelets.

Anus elliptical, transverse: situated at the end of a slight rostrum.

Tuberculation: of close-set, uniform granules with impressed areolæ.

Dimensions.	Laube's type.	B.M. E 1107.
Length	64 mm.	57 mm.
Width: at posterior third	56 „	48 „
„ anterior third	52 „	43 „
Height	36·5 „	33·5 „
Apical disc: distance from anterior end ...	25 „	23 „

Echinolampas posterocrassus, sp. nov. Pl. XIII. Figs. 4–6.

Form a depressed rounded pentagon: sides tumid. Apex a little behind the calycinal system; anterior slope gentle.

Apical system precentral; basal pores large: those of the posterior pair the further apart.

Ambulacra long, narrow: slightly petaloid but almost parallel:

open below. The pore pairs of the anterior pair slightly unequal. Those of the posterior pair markedly so.

Mouth anterior: in the highest part of the actinal depression: pentagonal: phyllodes very rudimentary.

Anus triangular: infra-marginal.

DIMENSIONS.

Length	43	mm.
Width: at $\frac{1}{3}$ of length from anterior end	36	,,
,, ,, posterior end	36·5	,,
Height	21	,,
Distance of apical disc from anterior end	17	,,
Length of petaloid portion of anterior ambulacrum	10	,,
Max. width of ,, ,, ,, ,,	3	,,
Length of petaloid portion of posterior ambulacrum: anterior poriferous area	17	,,
Length of petaloid portion of posterior ambulacrum: posterior area	12	,,
Max. width of ,, ,, ,, ambulacrum	3·5	,,

This species belongs to the group of Echinolampads of which *E. similis*, Ag., may be taken as the type. It differs from this by its greater proportional breadth, and the greater inequality of the poriferous zones in each of the posterior petals. It can be easily distinguished from other Australian species of this genus by its depressed form and the marked inequality in the length of the poriferous zones of the petaloid portions of the posterior ambulacra. Its general form reminds one of *Echinolampas dispar*, Fritsch,[1] from the Eocene of Borneo; from this it differs in that the mouth is more excentric in position, the anus is triangular (instead of round as in the Malaysian species), and in the latter the posterior part of the test is much wider than the anterior.

Fam. ANANCHYTIDÆ.

Genus *Cardiaster*, Forbes, 1852.

Cardiaster tertiarius, sp. nov. Pl. XIV. Figs. 2 & 3. B.M. E 3382.

Outline seen from above cordate: the test tapering gently posteriorly; the anterior end is broad, well rounded, and marked by the deep anterior groove. In elevation it is seen to be sloping steeply in front and very high behind; the posterior interradius is elevated into a slight keel. Vertex at a quarter of the length of the test from the anterior end. Posterior margin truncate and vertical, with the anus high upon this area. In this position the actinal surface appears straight.

Apical system central; elongate; only the right half is known.

Ambulacra flush: the pores of the posterior poriferous zones of each of the paired ambulacra larger than the anterior. Pores of unpaired anterior ambulacrum minute.

Tubercles crenulate and perforate.

DIMENSIONS.

Length	42	mm.
Width at $\frac{1}{3}$ length from anterior end of test	21	,,
,, ,, posterior ,,	18	,,
Height	25	,,

[1] K. von Fritsch, "Die Echiniden der Nummuliten-Bildungen von Borneo," Palæontographica, Supp. III. l. 1, Hft. 2, 1877, p. 89, pl. xiii. figs. 2 and 3.

Cardiaster has not hitherto been described except from the Cretaceous. The late Rev. J. E. Tenison-Woods recorded[1] the genus from Mt. Gambier, but gave neither figure nor description; and, as has been often pointed out, little value can be attached to his generic determination of Echinoidea. The present specimen is somewhat broken, and, as is so often the case in this genus, the fasciole cannot be seen; nevertheless the general form, the deep anterior groove, and the tuberculation, leave no doubt of its correct generic position.

The species agrees most closely with the European *C. ananchytis*, and most nearly with the variety *cordiformis*.[2] It differs, however, in the greater prominence of the ridges that bound the anterior groove; the test is higher, the anterior end is steeper, and instead of the gentle slope of the posterior interradium, this forms a horizontal keel, which is terminated abruptly by the almost vertical posterior margin.

Fam. SPATANGIDÆ.

Division *Prymnadete.*

Genus *Pericosmus*, Ag., 1847.

Sp. 1. *Pericosmus M'Coyi*, sp. nov.

Pericosmus compressus, M'Coy. Prod. Pal. Victoria, dec. vii. 1882, pp. 21–2, pl. lxvii. fig. 2, and lxviii. (Non *Megalaster compressus*, Dunc.)

Sp. 2. *Pericosmus compressus*, Dunc. sp. Pl. XIV. Fig. 1.

Megalaster compressus, Dunc. Q.J.G.S. 1877, vol. xxxiii. p. 62, fig. 1.

Prof. Duncan, in 1877, described as *Megalaster compressus* a large Spatangoid, evidently an ally of *Pericosmus*, but for which, owing to the absence of fascioles, he instituted a new genus. Prof. M'Coy five years later, in the course of his admirable figures and descriptions of the Victorian *Pericosmi*, named one species *P. compressus*, because he was deeply impressed with its resemblance to the specimen described by Dr. Duncan, and with the probability that *Megalaster* would turn out to be only a badly-preserved representative of this genus. Prof. von Zittel[3] seems previously to have entertained the same doubts, as he only accepted *Megalaster* with a query. Prof. Duncan, in his "Revision of the Australian Echinoidea," in 1887, referred to Prof. M'Coy's remarks, and after a brief discussion left the question open. In his recent "Revision of the Echinoidea,"[4] however, the genus is again quoted without any expression of doubt.

The question of the retention of the genus *Megalaster* depends upon whether the absence of fascioles in the type-specimen is due to their never having been developed or to their having been obliterated during weathering. The specimen has certainly been greatly worn; none of the tubercles on the abactinal surface are shown in Prof. Duncan's drawing, nor are they preserved in the British Museum specimen. It is therefore not surprising that

[1] J. E. Tenison-Woods, Geol. Obs. in South Australia, 1862, p. 77.
[2] Samuel Woodward, Geology of Norfolk, 1833, p. 50, pl. v. fig. 6.
[3] von Zittel, Handbuch der Palaeontologie, i. 1889, p. 541.
[4] Journ. Linn. Soc. Zool. xxiii. 1889, pp. 221-2.

fascioles cannot now be recognized; but in his discussion of the question Prof. Duncan emphasizes the fact that the specimen is certainly specifically distinct—quite apart from the fascioles—from any described species of *Pericosmus*. Prof. M'Coy, on the other hand, regarded it as probably identical with his *P. compressus*, though he noted that in addition to the fascioles the latter has a convexity, instead of a concavity, near the summit of the unpaired interradius.

In Mr. H. P. Woodward's collection there is a *Pericosmus* which agrees in the character noted by Prof. M'Coy, and in other points with Dr. Duncan's specimen. After a comparison of this with the specimen of *Megalaster*, I entertain no doubt that the two are specifically identical, and that consequently *Megalaster* must be abandoned.

As to the second question, whether *Pericosmus compressus*, Dunc. sp., is the same as *P. compressus*, M'Coy, I agree with Dr. Duncan rather than with Prof. M'Coy and Prof. Hutton. The two species differ in the following points: *P. compressus*, Dunc. sp., is longer than wide, whereas the other is wider than long: in the former the anteal sulcus is wider and shallower; the anus is oval instead of round; the anterior slope is steeper; the test is higher; the apical disc is more anterior; there is a concavity behind the apical disc; the ambulacra are less lanceolate, blunter and sinuous. These form a combination of characters that are quite sufficient to continue the separation of the species. But the absorption of *Megalaster* in *Pericosmus* necessitates the adoption of a new name for the later species. I have much pleasure in calling it after Prof. M'Coy, as, owing to his admirable work, his name must always be associated with the species; its renaming is only required owing to the perspicuity with which Prof. M'Coy interpreted Prof. Duncan's description and outline figure, and to the caution with which he hoped to save palæontological nomenclature from a useless synonym.

After Prof. Hutton's[1] remark, it is perhaps advisable to compare *P. M'Coyi* with the description of *Meoma crawfordi*, Hutton. The Australian species differs from the New Zealand one in that (1) it is not a *Meoma*; (2) it is broader than long—not longer than broad, as shown by Prof. Hutton's measurements; (3) the antero-lateral ambulacra are equal or slightly longer than the postero-lateral.

II.—Dr. Taylor's Collection. From the banks of the Murray River at Morgan.[2]

Fam. Arbaciidæ.

Gen. *Cœlopleurus*, Ag., 1840.

Cœlopleurus paucituberculatus, sp. nov. Pl. XIV. Figs. 4 and 5.

Test tumid; depressed abactinally; concave below. Circular.

[1] F. W. Hutton, "On the Correlations of the 'Curiosity-Shop Bed,' in Canterbury, New Zealand," Q J.G.S. 1885, vol. xli. p. 554.

[2] The sections at this point have been fully described by Prof. Tate in his "Notes on the Physical and Geological Features of the Lower Murray River," Trans. Roy. Soc. S. Australia, 1885, vol. vii. p. 35.

Apical system large; ornamented with tubercles; radials narrow. Anus slightly elliptical.

Ambulacra: narrow above with small tubercles; but wide at the ambitus with large tubercles; both sets are uncrenulate and imperforate. The bosses are large and fill up nearly the whole of the areola. Two rows of small flat granules run up the centre of each area at the ambitus, but disappear above. Eleven plates in a vertical series.

Interambulacra.—The bare median band at the summit of each area is bounded on either side by a row of large, and a row of small granules. At the ambitus the number of granules widen, and there are three rows of subequal granules on either side. No primary tubercles. Fifteen plates in the vertical series.

Mouth large; in a concavity. Buccal slits broad.

DIMENSIONS.

Diameter	19 mm.
Height	12 ,,
Width of ambulacral area at ambitus	7 ,,
Width of interambulacral	6 ,,
Diameter of anus	3 ,,

Distribution: Middle Murravian, Morgan, S. Australia (preserved in the Ipswich Museum).

Cœlopleurus is a typically Cainozoic genus, but has not previously been recorded from the Australian Tertiaries. The type-specimen of the new species is broken, but the apical disc and most of the abactinal surface, a complete ambulacrum and the halves of the two adjoining interambulacra are shown: all the points in the anatomy of the test can therefore be determined. *Cœlopleurus paucituberculatus* is very easily distinguished from any other species of the genus by the complete absence of primary tubercules on the interradii (the character which has suggested its name), and by the persistence to the apical disc of a pair of granules on either side of the bare median area. In the latter feature it resembles *Cœlopleurus sindensis*, Dunc. and Sl., which is apparently its nearest ally. It can be easily distinguished from this by the absence in the new species of the primary ambital interradial tubercles.

Fam. CLYPEASTRIDÆ.

Gen. *Clypeaster*, Lam., 1816.

Clypeaster gippslandicus, M'Coy.

Prod. Pal. Victoria, Dec. vi. 1879, pp. 33-5, pl. lix.

There is one well-marked specimen in the collection which is of interest, as the species is usually characteristic of the uppermost beds of the South Australian and Victorian Cainozoic series.

Subgen. *Monostychia*, Laube.

Monostychia australis, Laube, sp.

Sitz. k. Akad. Wiss. Wien. lix. Abth. i. 1869, p. 190, fig. 3.

The collection includes several specimens of this species, and one belonging to the var. *elongata*.

Fam. Spatangidæ.

Gen. *Hemiaster*, Desor, 1857.

Hemiaster planedeclivis, sp. nov. Pl. XIV. Figs. 6 and 7.

Pentagonal; thick with tumid sides: the abactinal surface is depressed and flat, and slopes gently forward from the vertex: the posterior side is steep, almost vertical.

Apical area excentric posteriorly: in front of the vertex. Construction not fully known: it is ethmolysian, and there are two large pores in the antero-lateral basals. The postero-lateral basals apparently also bear a pore each.

Ambulacra: the anterior is long and narrow with small pores: it is lodged in a slight depression. The petaloid portions of the lateral pairs are in broader and shorter depressions. The anterior pair are slightly sinuous and nearly twice as long as the posterior.

Fasciole: peripetalous: it is irregularly hexagonal: the anterior side broadens considerably in the middle. The fasciole is always wider where it traverses an ambulacrum.

Anus: high on the posterior margin.

Mouth: at a moderate distance from the anterior margin: the labrum is strongly projecting.

Dimensions.

Length	31 mm.
Width: at one-third length from anterior end ...	25 ,,
,, ,, ,, posterior end ...	28 ,,
Height	23 ,,
Length of anterior petal	9 ,,
Width of ,, ,, ...	3 ,,
Length of posterior petal	5 ,,
Width of ,, ,, ...	2 ,,
Apical disc: distance from anterior end	18 ,,

Distribution. — Middle Murravian, Morgan, South Australia (preserved in the Ipswich Museum).

Remarks.—*Hemiaster planedeclivis* is a species of a very Cretaceous aspect, and its closest affinity is with the group of which *H. fourneli*, Desh.,[1] *H. nucleus*, Des.,[2] and *H. palpebratus*, Lor.,[3] are typical representatives: it has the high posterior vertex, the tumid sides, the flat abactinal surface, the almost vertical posterior margin, the small posterior petals, and well-developed labrum which is characteristic of this group. Nevertheless it differs clearly from any described species; thus from *H. palpebratus* it can be readily distinguished by the greater flatness of its abactinal surface, and the absence of the tumid antero-lateral interradii seen in that species. The widely-distributed *H. fourneli* is probably its nearest ally, and from this it may readily be separated by its greater breadth and the flatness of the upper side. From the whole of this group of *Hemiasters*, in fact, the flatness of the abactinal slope, the proportions of the pairs of petals, and the irregularity of the fasciole form a combination of characters that enable this species to be easily distinguished.

[1] Agassiz and Desor, Catalogue raisonné, pt. 3, Ann. Sci. nat. (3) viii. 1847, p. 16.

[2] Agassiz and Desor, *op. cit.* p. 17.

[3] De Loriol. Faune crétacique du Portugal, Echinodermes, II. fasc. 2, Lisbon, 1888, pp. 103-4, pl. xx. figs. 1-3.

The genus *Hemiaster* has not been hitherto described from Australia, but a species is known from New Zealand. *H. planedeclivis* belongs, however, to a very different group to this *H. posita*, Hutton,[1] which has a cordate, inflated test, with the pores on the inner side of the postero-lateral ambulacra obliterated near the apical area. Moreover, the latter species is said in the diagnosis to have neither subanal nor peripetalous fasciole. If this be correct, the species is not a *Hemiaster*, but must be transferred to the genus *Epiaster*.

The generic determination of this Echinoid may be considered doubtful by the French palæontologists who separate from *Hemiaster* all the Cainozoic forms. But apart from the disputed question of the validity of the new genera to which these species are referred, the affinities of *H. planedeclivis* are so distinctly with the Cretaceous group that it must be regarded as a true typical *Hemiaster*.

III.—From Nullarbor Plains.

During the exploration of the country between Port Augusta and Eucla,[2] a few Echinoidea were collected from the Nullarbor limestone; these have also been presented to the British Museum (Nat. Hist.) by H. Y. L. Brown, Esq. At Tallowan Well in the Fowler's Bay district an *Echinolampas*, sp., and some fragments probably referable to *Eupatagus* were collected. The other specimens were without definite locality: they are *Echinus woodsi*, Laube, and *Lovenia forbesi* (Woods and Dunc.).

IV.—The Affinities of the Echinoid Fauna.

Many attempts have been made to classify the Australian Cainozoic deposits, and to establish definite correlations of the beds of the various localities with each other, and with the European formations; no very definite classification has, however, as yet been agreed upon. But an examination of the faunal lists clearly shows that various horizons are represented, and until the relations of these are at least approximately known, no definite conclusions as to the affinities of the fauna can be established.

As Mr. Woodward's collection was made at a new locality, it is necessary to consider the relations of the fauna to those from other places in South Australia and Victoria. Of the five recognizable species three are new, but the other two are well-marked forms; they suggest that the beds belong to the lowest of the three divisions into which it seems generally agreed that these Australian Cainozoic deposits can be divided. As to the terms to be applied to these divisions, however, opinions differ greatly. The banks of the Murray River exhibit the longest continuous sections, and afford the best oppor-

[1] F. W. Hutton, Cat. Tert. Mollusca and Echinodermata of New Zealand, New Zealand Geol. Surv., Miscell. Publications, No. IX. 1873, p. 42. Hector, Cat. of Geol. Exhibits, New Zealand Court, India and Colonies Exhibition, London, 1886, p. 54, fig. 1.

[2] H. Y. L. Brown, "Report of Country passed over from Port Augusta to Eucla," Adelaide, 1885.

tunity for the working out of the sequence of palæontological zones; it is therefore probable that this series will serve as the scale with which the disconnected beds of other localities will be compared; hence Prof. Tate's terms,[1] Upper, Middle and Lower Murravian, may be conveniently adopted. The beds at Mordillac, and some other Gippsland localities belong to the highest part of the marine Cainozoics, and their correlation with the Upper Murravian seems generally admitted. The beds at Mount Gambier, Wauru Ponds, Muddy Creek, Geelong, Bird Rock Point, and Cape Otway are referred to the Middle Murravian; no serious effort to establish a precise correlation of the beds at these localities seems to have been made, but their Echinoid faunas have much in common; thus of the four species from Mount Gambier, three occur in the middle division of the Murray River beds, and the fourth occurs at Cape Otway; of the four at Cape Otway, one (*Holaster difficilis*—an unsatisfactory species) is peculiar, one occurs at Mount Gambier, and the other two in the Middle Murravian of the typical locality.

The collection made by Mr. Woodward has a somewhat oldish facies: *Pericosmus compressus* (Dunc.) is elsewhere commonest in the Lower Murravian beds, while the species characteristic of the upper division are absent. Hence though the evidence is insufficient for any positive opinion, it is probable that the beds at this point will turn out to be Lower Murravian.

When considering the distribution of the Australian Cainozoic Echinoidea, one must compare them with those from New Zealand made known to us by the labours of Prof. von Zittel[2] and Prof. F. W. Hutton.[3] The latter has described a fauna from the Curiosity Shop beds, which in its main features greatly resembles that of South Australia and Victoria, while some of the species are regarded as identical. The brief diagnoses given by Prof. Hutton do not, in the absence of illustrations, allow of any close comparison being made between them and the Australian species: nevertheless the resemblances are sufficient to show that they are of approximately the same age, and to necessitate their inclusion in any full consideration of the relations of the fauna.

The attempt to correlate the Murravian beds with their European equivalents is of course much more difficult than their classification. Prof. Duncan, distrusting the application of European terms in such distant regions, calls the Mount Gambier beds Middle Cainozoic, those below that horizon the Lower, and those above the Upper Cainozoic.[4] Profs. Selwyn and M'Coy and the authors of Skene's map of Victoria, agree in the main with Prof. Duncan, though they call the Gippsland beds Pliocene and the others Miocene and

[1] Tate, "Notes on the Correlations of the Coral-bearing Strata of South Australia," Trans. Roy. Soc. South Australia, vol. i. 1878, pp. 120–3.

[2] K. von Zittel, "Neue Mollusken und Echinodermen aus Neu-Seeland," Novara Reise, Palaeontologie.

[3] F. W. Hutton, "Catalogue of the Tertiary Mollusca and Echinodermata of New Zealand," New Zealand Geol. Soc., Miscell. Public. ix. 1873.

[4] P. M. Duncan, "On the Fossil Corals of the Australian Tertiary Deposits," Q.J.G.S. xxvi. 1870, p. 315.

Oligocene: as long as we regard these terms as implying only a general homotaxis, they are synonymous with and more convenient than the others. Professor Hutton[1] however assigns his New Zealand Echinoidea to the Cretaceo-Tertiary; but the fact that more than 20 per cent. of the species from this horizon are still living would appear to conclusively negative this opinion. Prof. Hutton, however, in his latest note,[2] correlates the Cobden with the Ototara limestone, and says that the fossils "indicate an Upper Eocene or Lower Miocene, *i.e.* an Oligocene age." Prof. Tate's conclusions[3] are rather intermediate between the two extremes of Prof. M'Coy on the one hand and Prof. Hutton's earlier paper on the other: he correlates the Upper Murravian as Miocene and the Middle Murravian as Eocene. Mr. Dennant[4] again would make the beds older. As the Upper Muddy Creek beds, including Mordillac, contain only 6·5 per cent. of living species, he assigns them to the Oligocene, and the lower beds with 1·5 per cent. to the Lower Eocene. Nummulites, it may be remarked, also occur on this horizon. The Echinoidea seem to support the views of Mr. Dennant. The presence of so many genera peculiar to or characteristic of the Cretaceous, such as *Cassidulus*, *Catopygus*, *Cardiaster*, *Holaster*, and *Micraster*, and the closer alliance of some species, as *H. planedeclivis*, to the Cretaceous rather than the Tertiary representatives of their genera, suggest that the fauna is early Tertiary.

Some other genera, as *Cœlopleurus* and *Echinolampas*, are characteristically Eocene, and some peculiar forms have their nearest allies in the same period: further the absence of the typical Upper Tertiary genera is very noticeable; both of these points strengthen the same conclusion. Moreover, as far as the Echinoidea go, the differences of the faunas of the Upper and Lower Murravian are too slight to allow one to consider them as separated by so long a period as that between the Eocene and the Pliocene; there is certainly nothing in the Echinoid fauna that would debar the uppermost beds from entering the Oligocene.

But the real correlation of these beds will depend more on the Mollusca than on the Echinoidea: the latter are so anomalous a collection that little faith can be attached to their evidence on this subject. The interest of the fauna depends on its bearing on other problems. It seems to be composed of two constituents: about a third are species of the ordinary Palæarctic Upper Cretaceous genera; these seem to have migrated southwards and became mingled on their journey with a fauna that agrees most closely with that of the Eocenes of India and Malaysia. No abyssal types were picked up on the march, nor do any of the species retain any

[1] F. W. Hutton, Q.J G.S. xli. 1885, pp. 558-64.

[2] "On some Fossils lately obtained from the Cobden Limestone at Greymouth," Trans. N. Zealand Inst. xx. 1888, pp. 267-9.

[3] Tate, "Census of the Fauna of the Older Tertiary of Australia," Journ. R. Soc. N. S. Wales, xxii. 1888, pp. 242.

[4] J. Dennant, "Notes on the Muddy Creek Beds, with Brief Remarks on other Tertiary Strata of S. Western Victoria," Trans. R. Soc. S. Australia, vol. xi. 1889, pp. 53-4.

trace of the influence of a deep-sea habitat. Hence the route may have followed the coasts of Asia and Malaysia, in which case we may hope for much further light to be thrown upon its progress by collectors in that area; or the line may have lain across what is now occupied by the deep abysses of the Indian Ocean, but if so it must have occurred before its bed had subsided to anything like its present depth.

EXPLANATION OF THE PLATES.

PLATE XIII.

FIGS. 1, 2, and 3. *Cassidulus longianus*, sp. nov., Willunga, S. Australia. Nat. size. Brit. Mus. E 3380. Fig. 1. Abactinal view. Fig. 2. Actinal view of another specimen. Fig. 3. Side view of former specimen.

FIGS. 4, 5, and 6. *Echinolampas posterocrassus*, sp. nov., Willunga. Nat. size. Brit. Mus. E 3381. Nat. size. Fig. 4. Side view. Fig. 5. Abactinal view. Fig. 6. Actinal view of same specimen.

FIGS. 7 and 8. *Echinolampas ovulum*, Laube. Bairnsdale, Victoria. Brit. Mus. E 1107. Nat. size. Fig. 7. Actinal view. Fig. 8. Side view of same specimen.

PLATE XIV.

FIG. 1. *Pericosmus compressus* (Dunc.). Willunga. Brit. Mus. E 3383. Half size.

FIGS. 2 and 3. *Cardiaster tertiarius*, sp. nov. Willunga. Brit. Mus. E 3382. Nat. size. Fig. 2. Abactinal. Fig. 3. Side view of same specimen.

FIGS. 4 and 5. *Cœlopleurus paucituberculatus*, sp. nov. Morgan, S. Australia. Fig. 4 × 2 dia. Fig. 5. Diagram of apical disc and surrounding plates × 4 dia. Ipswich Museum.

FIGS. 6 and 7. *Hemiaster planedeclivis*, sp. nov. Morgan, S. Australia. Nat. size. Ipswich Museum.

II.—QUATERNARY CHANGES OF LEVELS.

By WARREN UPHAM,
of the United States Geological Survey.

THE article by Prof. J. W. Spencer in the last May number of this MAGAZINE brings together many evidences of high continental elevation of North America preceding the Pleistocene or Glacial period. Though Professor Spencer has not proceeded to interpret these observations as revealing in continental elevation the probable cause of the severely cold climate and accumulation of ice-sheets during the Glacial period, I believe that this is a legitimate conclusion, and that it strongly re-enforces the arguments long ago advanced by Lyell and Dana, and recently emphasized anew by Wallace.

But certain other observations bearing on the length of the Postglacial or Recent epoch lead me to differ from Wallace, who combines high elevation with maximum eccentricity of the earth's orbit as necessary concomitant conditions of glaciation. Closely accordant computations of the length of Postglacial time have been reached quite independently by Prof. N. H. Winchell, from the rate of recession of the Falls of Saint Anthony;[1] by Dr. E. Andrews, from

[1] Quart. Journ. Geol. Soc., vol. xxiv. 1878, pp. 886-901; Geology of Minnesota, Fifth Annual Report, for 1876; and Final Report, vol. ii. 1888, pp. 313-341, with numerous plates and maps.

the rate of erosion of the shores of Lake Michigan and the resulting accumulation of beach sand blown into dunes at the south end of the lake;[1] by Prof. G. F. Wright, from the rate of filling of small peat bogs in hollows surrounded by kames and osars at Andover, Mass., and from the erosion of streams tributary to Lake Erie;[2] by Mr. G. K. Gilbert, from the recession of Niagara Falls;[3] and by Prof. B. K. Emerson, from the rate of deposition of modified drift in the Connecticut valley at Northampton, Mass.[4] These measurements and estimates agree in showing that only 6,000 to 10,000 years have passed since the ice-sheet of the last Glacial epoch was melted away from the northern part of the United States. It is therefore impossible to refer that glaciation to an epoch of increased eccentricity which ended 80,000 years ago. An equally small estimate is also indicated by the studies of Gilbert[5] and Russell[6] for the time since the last great rise of Lakes Bonneville and Lahontan, which appear to have fluctuated contemporaneously with the growth and departure of the North American ice-sheets.

In Wales and Yorkshire the amount of denudation of limestone rocks on which boulders lie has been regarded by Mr. D. Mackintosh as proof that a period of not more than 6000 years has elapsed since the boulders were left in their present positions.[7] The vertical extent of this denudation, averaging about six inches, is nearly the same with that observed in the south-west part of the Province of Quebec by Sir William Logan and Dr. Robert Bell, where veins of quartz marked with glacial striæ stand out to various heights not exceeding one foot above the weathered surface of the enclosing limestone.[8]

Another indication that the final melting of the ice-sheet upon British America at the close of the last Glacial epoch was separated by only a very short interval, geologically speaking, from the present time, is seen in the wonderfully perfect preservation of the glacial striation and polishing on the surfaces of the more enduring rocks. Of their character in one noteworthy district, Dr. Bell writes as follows:—"On Portland promontory on the east coast of Hudson's Bay, in latitude 58°, and southward, the high rocky hills are completely glaciated and bare. The striæ are as fresh-looking as if the ice had left them only yesterday. When the sun bursts upon these

[1] Transactions of the Chicago Academy of Sciences, vol. ii. James C. Southall's "Epoch of the Mammoth and the Apparition of Man upon the Earth," 1878, chapters xxii. and xxiii.

[2] Am. Journ. Sci. III. vol. xxi. pp. 120-3, Feb. 1881; "The Ice Age in North America," 1889, chapter xx. p. 466.

[3] Nature, vol. xxxiv. p. 560; Proc. Am. Assoc. for Adv. of Science, vol. xxxv. for 1886, p. 222; "The History of the Niagara River," Sixth Ann. Rep. of Commissioners of the State Reservation at Niagara, for 1889, pp. 61–84.

[4] Am. Journ. Sci. III. vol. xxxiv. pp. 404-5, Nov. 1887.

[5] U.S. Geol. Survey, Second Annual Report, p. 188.

[6] U.S. Geol. Survey, Monograph xi. "Geological History of Lake Lahontan," p. 273.

[7] Quart. Journ. Geol. Soc. vol. xxxix. 1883, in Proceedings, pp. 67–69. Compare *id.* vol. xlii. 1886, pp. 527–539.

[8] Bulletin of the Geological Society of America, vol. i. 1889, p. 306.

hills after they have been wetted by the rain, they glitter and shine like the tinned roofs of the city of Montreal."[1]

Debarred by the shortness of the Postglacial epoch from attributing the Ice Age to the astronomic condition of maximum eccentricity, so ably advocated by Croll, we must look for other causes of this extraordinary geological period; and these seem to be found in great uplifts of the glaciated areas, of which for North America Prof. Spencer has given an impressive review. The submarine border of the continental plateau to depths of more than 3000 feet is cut by valleys or channels, which if raised above the sea-level would be fjords or cañons. These can be no other than river-courses eroded while the land stood much higher than now; and its subsidence evidently took place in a late geologic period, else the channels would have become filled with sediments.

According to the United States Coast Survey charts, as noted by Spencer, the bottom of a submerged valley just outside the delta of the Mississippi is found by soundings at the depth of 3000 feet. This valley is a few miles wide, and is bounded by a plain of the sea-bed from 900 to 1200 feet above its floor. It thus appears that the country north of the Gulf of Mexico has been raised for a short time to a height of not less than 3000 feet; and it is important to note in passing that an equal uplift would wholly close the Strait of Florida, 2064 to 3000 feet deep, through which the Gulf Stream now pours into the North Atlantic.

The continuation of the Hudson River valley has been traced by detailed hydrographic surveys to the edge of the steep continental slope at a distance of about 105 miles from Sandy Hook. Its outermost 25 miles are a submarine fjord three miles wide and from 900 to 2250 feet in vertical depth, measured from the crests of its banks, which with the adjacent flat area decline from 300 to 600 feet in depth below the present sea-level. The deepest sounding in this fjord is 2844 feet.[2]

An unfinished survey by soundings off the mouth of Delaware Bay finds a similar valley submerged nearly 1200 feet, but not yet traced to the margin of the continental plateau.

Again, the United States Coast Survey and British Admiralty charts, as Spencer states, record submerged fjord outlets from the Gulf of Maine, the Gulf of Saint Lawrence, and Hudson Bay, respectively 2664 feet, 3666 feet, and 2040 feet below sea-level. The bed of the old Laurentian River from the outer boundary of the Fishing Banks to the mouth of the Saguenay, a distance of more than 800 miles, shown by Professor Spencer's map, is reached by soundings 1878 to 1104 feet in depth. Advancing inland, the sublime Saguenay fjord along an extent of about fifty miles ranges from 300 to 840 feet in depth below the sea-level, while in some places its bordering cliffs, one to one and a half miles apart, rise abruptly 1500 feet above the water.[3]

[1] *Id.* p. 308.

[2] Rep. of U.S. Coast and Geodetic Survey, 1884, pp. 435–8, with map and profile; also in Amer. Journ. Sci. III. vol. xxix. pp. 475–480, June, 1885. Compare Bulletin Geol. Soc. Am. vol. i. 1889, pp 563–7.

[3] J. W. Dawson, "Note on the Post-Pliocene Geology of Canada," 1872, p. 41.

Greenland is divided from the contiguous North American continent and archipelago by a great valley of erosion, which is estimated from soundings and tidal records to have a mean depth of 2510 feet below sea-level for 680 miles through Davis Strait; 2095 feet for 770 miles next northward through Baffin Bay; and 1663 feet for the next 55 miles north through Smith Strait.[1]

On the Pacific coast of the United States, Professor Le Conte has shown that the islands south of Santa Barbara and Los Angeles, now separated from the mainland and from each other by channels 20 to 30 miles wide and 600 to 1000 feet deep, were still a part of the mainland during the late Pliocene and early Quaternary periods.[2]

In northern California, Professor Davidson of the U.S. Coast Survey, as cited by Spencer, reports three submarine valleys about 25, 12, and 6 miles south of Cape Mendocino, sinking respectively to 2400, 3120, and 2700 feet below the sea-level where they cross the 100 fathom line of the marginal plateau. If the land here were to rise 1000 feet, these valleys would be fjords with sides towering high above the water, but still descending beneath it to profound depths.[3]

Farther to the north, Puget Sound and the series of sheltered channels and sounds through which the steamboat passage is made to Glacier Bay, Alaska, are submerged valleys of erosion, now filled by the sea, but separated from the open ocean by thousands of islands, the continuation of the Coast Range of mountains. From the depths of the channels and fjords Dr. G. M. Dawson concludes that this area had a Preglacial elevation at least about 900 feet above the present sea-level, during part or the whole of the Pliocene period.[4]

The general absence of Pliocene formations along both the Atlantic and Pacific coasts of North America indicates that during this long period all of the continent north of the Gulf of Mexico held a greater altitude, which, from the evidence of these submarine valleys, is known to have culminated in an elevation at least 3000 feet higher than that of the present time. Such plateau-like uplift of the whole continent appears to have exerted so great influence on its meteorologic conditions, bringing a cooler climate throughout the year, that it finally became enveloped by an ice-sheet to the southern limit of the glacial striæ, till, and moraines, stretching from Nantucket and Cape Cod to New York, Cincinnati, Saint Louis, Bismarck, and thence westward to the Pacific somewhat south of Vancouver Island and Puget Sound. The thickness of the ice-sheet in the region of the White Mountains and the Adirondacks was about one mile; and Dana has shown, from the directions of striation and transportation of the drift, that its central portion over the Laurentian highlands between Montreal and Hudson Bay had probably a thickness of fully two miles. In British Columbia,

[1] Smithsonian Contributions to Knowledge, vol. xv. pp. 163, 164.
[2] Bulletin of the California Academy of Sciences, vol. ii. 1887, pp. 515–520.
[3] *Id.* vol. ii pp. 265–8.
[4] Canadian Naturalist, new series, vol. viii. pp. 241–248, April, 1877.

according to Dr. G. M. Dawson's observations, it covered mountain summits 5000 to 7200 feet above the sea.[1]

While thus heavily ice-laden, nearly the whole glaciated area sank below its present level, but for the most part only to a slight amount in comparison with its previous elevation. Beginning at a line drawn north-eastward through New York, Boston, and Nova Scotia, the extent of the submergence of the land by the sea at the time of recession of the ice-sheet, as shown by fossiliferous marine deposits overlying the till, increases from 150 and 225 or 230 feet on the coast of New Hampshire and Maine to 520 feet at Montreal; 300 to 500 feet on the country south-west of James Bay; and about 1500 feet, according to Dr. Robert Bell, at Nachvak on the eastern coast of Labrador. In British Columbia, including Vancouver Island and the Queen Charlotte Islands, Dr. Dawson finds evidence of submergence to the amount of 200 or 300 feet while the glacial conditions still endured. During Postglacial time the Atlantic and Pacific coasts have been again uplifted, attaining generally a somewhat greater height than now, the most recent movements being mostly subsidence. But in the basin of Hudson Bay, and probably also in Labrador and northward, the uplift from the glacial depression is still in progress.[2]

In the interior of the continent, the northward ascent of the beaches of the glacial Lake Agassiz shows that the differential uplift attending the departure of the ice-sheet amounted to about one foot per mile, increasing from south to north or north-north-east, in the Red River Valley and the basin of Lake Winnipeg, for 400 miles from Lake Traverse to the north end of Duck Mountain.[3]

On account of the same upward movement, the beach formed by Lake Ontario when it was dammed on the north-east by the receding ice upon the area of the Adirondacks, the Thousand Islands, and the Ottawa basin, is found by Gilbert to have an ascent of three feet per mile north-eastward about the west end of this lake and along its south side, with increase to four or five feet per mile about its east end. The Postglacial tilting of the old beaches of Lake Erie, and similar changes that have been studied by Chamberlin in Wisconsin between Lakes Michigan and Superior, seem to present less regularity, probably because the restoration of equilibrium of the earth's crust is combined with independent crustal movements and strains, whereby a large part of the glacial depression of the basins of these lakes is still retained. The beaches and deltas of a small glacial lake in the valley of the Contoocook River, New Hampshire, have a northward rise of about five feet to the mile

[1] Geol. Mag. Dec. III. Vol. VI. 1889, pp. 350–2.

[2] For a more detailed review of these Postglacial oscillations, and of Quaternary movements of uplift and subsidence in other parts of the world, both in glaciated and unglaciated regions, see Prof. G. F. Wright's "Ice Age in North America," 1889, Appendix by Warren Upham, pp. 573–595.

[3] Geol. Mag. Dec. II. Vol. X. 1883, pp. 427–8; Dec. III. Vol. IV. 1887, pp. 344–8; Vol. VI. 1889, p. 37. Geology of Minnesota, vols. i. and ii. Bulletin 39, U.S. Geol. Survey. Geol. and Nat. Hist. Survey of Canada, Annual Report, vol. iv. for 1888–89, Part E.

along its extent of fifteen miles;[1] and the average of the differential uplift between Boston and Montreal, a distance of about 250 miles, is approximately two feet per mile.

North-western Europe also had a much greater altitude during the later part of the Tertiary era, in which Scandinavia and the British Isles suffered vast denudation, with erosion of fjords and channels that are now submerged 500 to 800 feet beneath the sea.[2] Probably many of these submarine channels are now more or less filled with the glacial drift, so that valleys originally descending continuously toward the margin of the continental plateau have become in some portions changed to enclosed basins. The maximum Preglacial elevation must have exceeded the depth of the Skager Rack between Denmark and Norway, which is 2580 feet, with a deep submerged valley running from it west and north to the abyssal Arctic Ocean.[3]

Under the weight of its ice-sheet, the glaciated area of Europe, like that of North America, sank mostly to a somewhat lower level than it now has, the maximum depression being on the coast of Norway, about 580 feet.[4] From this depression Scandinavia has gradually risen, with pauses during which beaches were formed; and the uplift of that country continues to the present day, as of the region about Hudson Bay.[5]

III.—Notes on the Bunter and Keuper Formations in the Country around Liverpool.[6]

By G. H. Morton, F.G.S.

THE Bunter and Keuper formations of the Trias are very fully developed in the country around Liverpool, and leaving out of consideration the Red Marl, both of these formations seem to be thicker there than anywhere else in Great Britain. The object of this paper is to give a few notes recording the thickness of the Trias, the structure of the various sandstones of which it is composed, and the character of the included pebbles, many of which are of local derivation.

Excavations and borings have been in constant progress for many years, so that every bed in the Trias has been exposed and on most horizons many times in succession, and it is now possible to tell exactly the strata to expect at any given depth when once those at the surface are ascertained.

The following section shows the succession and relative thickness

[1] Geology of New Hampshire, vol. iii. 1878, pp. 103–120.

[2] James Geikie, Q.J.G.S. vol. xxxiv. 1878, pl. xxxiii. "The Great Ice Age," second edition, pp. 279–284, with plates ix.—xii.

[3] Nature, vol. xxiii. p. 393, with map of submarine contour.

[4] Geol. Mag. Dec. III. Vol. VI. 1889, pp. 157, 158; Nature, vol. xxxii. p. 555.

[5] Nature, *loc. cit.*; and vol. xxxix. pp. 488–492.

[6] Read at the British Association, Leeds, September, 1890.

of each subdivision of the Bunter and Keuper derived from railway cuttings and tunnels, borings for water and coal-pits.

			Feet.
Trias	Keuper, 800 feet	Red Marl	400
		Keuper Sandstone ...	400
	Bunter, 1950 feet	Upper Soft Sandstone ...	550
		Upper Pebble-beds ...	400
		Lower Pebble-beds ...	600
		Lower Soft Sandstone ...	400
			2750

The whole thickness in 1863 was supposed to be about 1700 feet, and was obtained from the measurement of outcrops of the strata, but it is now proved to be 2750 feet. The Red Marl at the top of the Keuper, and the Lower Soft Sandstone at the bottom of the Bunter, however, vary in thickness from a few to 400 feet.

Microscopic Structure.

In each of the subdivisions of the Trias the sandstones present a typical character, though it often happens that some interstratified beds of a softer or harder nature occur and differ from those forming the rest of the strata. A few specimens from any subdivision will often indicate the horizon to which they belong, but it must not be supposed that a single piece of the sandstone is sufficient for the purpose.

In a series of beds of sandstone 2350 feet in thickness, excluding the Red Marl, and which vary on the same horizon in different localities, it is difficult to draw general conclusions of much value The microscopic examination, however, of a great number of specimens from many horizons in the Trias about Liverpool shows that there are five normal types, although they run, more or less, into each other.

Firstly—Coarse-grained sandstone, composed of rounded and subangular grains of quartz, larger than $\frac{1}{100}$th of an inch in diameter.

Secondly—Fine-grained sandstone, composed of rounded and subangular grains of quartz smaller than $\frac{1}{100}$th of an inch in diameter.

Thirdly—Coarse-grained sandstone, containing a great number of large grains of quartz $\frac{1}{25}$th to $\frac{1}{35}$th of an inch in diameter, like a minute conglomerate.

Fourthly—Coarse-grained sandstone, composed of rounded, subangular and crystallized grains of quartz—the crystallized faces having been deposited on the original grains after the sandstone was formed.

Fifthly—Coarse-grained sandstone, or quartzite, originally formed of rounded and subangular grains which have been united by the deposition of silica into a hard rock after the formation of the sandstone.

All these sandstones contain, in addition to the grains described, a great number of small splintery fragments of quartz down to $\frac{1}{1000}$th of an inch in diameter and so fine as to resemble dust.

In the Bunter formation, the Lower Soft Sandstone is very similar to the Upper Soft Sandstone in general appearance, but it is coarser and the average size of the grains is larger than $\frac{1}{100}$th of an inch in diameter. The chief distinction is the frequent occurrence of large rounded grains from $\frac{1}{25}$th to $\frac{1}{35}$th of an inch in diameter in a matrix of smaller ones, but they are not always present and seem peculiar to the subdivision in South-West Lancashire. Strata at Croxteth, Tarbock and Rainford belonging to the Lower Soft Sandstone contain these large seed-like grains, embedded in a coarse-grained matrix, but generally so loose that the rock has a soft sandy character. At Knowsley the grains are held together by secondary quartz and a quartzite of extreme hardness is the result. Kaolin is always present and often some mica.

The Lower and Upper Pebble-beds are formed of sandstone composed of coarse rounded and subangular worn and crystallized grains of quartz, associated with minute splintery fragments. Kaolin in the form of grains and dust forms a conspicuous portion of the rock. . The typical sandstone of the Pebble-beds is almost a true grit formed of angular grains, but the angularity is in consequence of the crystallization of secondary quartz in planes and angles over the exterior of the originally rounded grains in optical continuity.[1] The hardness and toughness of the Pebble-beds as a building-stone is due to their compact and felted structure—the interstices between the grains being filled up with a fine dust of quartz and kaolin and the whole cemented together by ferric-oxide and silica. The grains of quartz are generally from $\frac{1}{30}$th to $\frac{1}{250}$th of an inch in diameter, besides a vast number of splintery fragments. In addition to kaolin, mica and a few other minerals occur.

The Upper Soft Sandstone is principally composed of small rounded grains of quartz, varying from $\frac{1}{100}$th down to minute fragments $\frac{1}{500}$th of an inch in diameter. The structure is of a loose sandy character, so that the sandstone soon disintegrates on exposure to the weather. The highest beds are coarser than the mass of the Upper Soft Sandstone, and occasional grains occur from $\frac{1}{35}$ to $\frac{1}{50}$ of an inch in diameter as at Scarth Hill near Ormskirk, Flaybrick Hill and Crown Street, Liverpool, but they are so rare that they are not characteristic of the subdivision. Kaolin is always present and usually a few flakes of mica. The finer grain of the Upper, compared with the Lower Soft Sandstone, is well shown by placing a series of specimens from each subdivision and from different localities, together, when the average finer grain of the latter is obvious.

The Keuper Sandstone varies considerably in its microscopical structure, and that near the base cannot be distinguished from that of the Pebble-beds. The lower beds of the Keuper Sandstone are composed of large, rounded, subangular grains of quartz, many of which are covered with crystallized faces of a more recent origin. Higher in the subdivision the sandstone is often formed of rounded

[1] The formation of crystals on grains of quartz in sandstone was first described by Prof. T. G. Bonney, F.R.S., in Q.J.G.S. vol. xxxv. p. 666.

grains and much resembles that of the Upper Soft Sandstone, though usually much harder. There are, however, other beds, about the middle of the Keuper Sandstone, remarkable for the large proportion of kaolin they contain and the occurrence of crystallized grains.

Although there is a difference between the quartz grains and the relative proportion of kaolin associated with them in the sandstones described, the chief distinction is in consequence of chemical changes that have altered the sandstones since their deposition.

The original felspar grains have been usually decomposed and the silica so liberated deposited in optical and crystalline continuity on the grains of quartz, while the percolation of water containing ferric-oxide produced the various shades of red and yellow, and both the silica and the iron form the cementing material with which the grains are united. The great diversity in the colour and the variegated appearance frequently seen, particularly about the base of the Keuper, and the variation in the tenacity with which the grains are held together in the Triassic Sandstones generally are interesting subjects for investigation and often very difficult to explain.[1]

Pebbles in the Trias.

The only pebbles that occur in the Bunter formation in the country around Liverpool are found in the Lower Pebble-beds, and considering the great thickness and the large area over which the subdivision occurs, the variety is by no means remarkable and very much alike in different localities. Most of the pebbles are less than an inch across and very few reach the diameter of six inches. They consist principally of white vein quartz, quartzite, and a few other rocks and minerals. Nearly all are of a round or oval form, perfectly smooth and must have come from a great distance, and most probably from the Cambrian and Silurian rocks of Central England or Scotland. Next in frequency, though relatively few, are rough pebbles and angular fragments of coarse felspathic grit, sandstone, and chert, resembling beds in the Cefn-y-Fedw Sandstone, Millstone Grit, and Coal-measures within twenty miles from Liverpool. They could not have travelled far, and may have been derived from strata at a less distance. Although it is assumed that the Coal-measures to the east and north-east were covered by the Trias, it is certain that they had been denuded about Parbold, Knowsley and much of Flintshire, before the latter formation was deposited on the Millstone Grit.

At Middle Island and Hilbre Point, near Hoylake, there are beds of breccia containing angular fragments of vein quartz, grit, and sandstone, associated with strata containing scattered pebbles of the quartzite characteristic of the Lower Pebble-beds. Similar brecciated beds occur at Little Mollington, near Chester, but the fragments are smaller than those at Hilbre. At Cuckoo Hill, near Hope in Flintshire, the sandstones and shales of the Millstone Grit are well exposed with the Lower Soft Sandstone resting against them, and the lowest beds of the latter form a breccia several feet thick of angular fragments from the underlying strata.

[1] "Iron as a Colouring Matter of Rocks," by A. Norman Tate, F.C.S., Proc. Liverpool Geol. Soc. vol. v. p. 284.

During the last three years, at the suggestion of Prof. Bonney, I collected a large number of pebbles from the Lower Pebble-beds of the Bunter and from the base of the Keuper Sandstone—selecting the following localities as those where pebbles were most abundant, viz. Eastham, Hilbre, Redstones, Hilbre Point, Pool Hall Rocks, Rainhill, Thatto Heath and Woolton in the Bunter; and Bidston Hill, Flaybrick Hill, Oxton, Wallasey and West Kirby in the Keuper.

The pebbles in the Lower Pebble-beds include many of white vein quartz and a few of a red shade. The quartzite pebbles vary considerably in colour and range from white to grey and black, and from white to pink, red, brown, and the well-known liver-coloured quartzite, but the latter is not common. Some of them are coarse and others fine-grained, and the latter usually fracture through the grains embedded in the matrix. These are felspathic grits which Prof. Bonney considers of the "Torridon Sandstone" type, and others resembling the Millstone Grit. Hälleflinta and black slaty rock sometimes with white quartz veins are frequent. Quartz-felsites occur, but generally in a decomposed condition. Sandstone like that of the Upper Silurian is frequent.[1] A single specimen of pink granite was found, and a pebble of white orthoclase with the cleavage remarkably bright and fresh.[2] A pebble of black chert and another of cherty mudstone resembling beds in the Cefn-y-Fedw Sandstone were also found. The largest pebbles measured six inches in length, and they were of both quartz and quartzite, but it is seldom that they occur so large. Small bits, large rounded lumps and thin partings of shale and marl are of frequent occurrence.

The pebbles in the Keuper Sandstone occur almost entirely about the base of the formation, but they are few in number compared with those in the Bunter. There are pebbles of white vein quartz, and a few have yellow and red stains. The quartzite pebbles are mostly white, and possess a glistening external appearance in consequence of the irregular fracture of the embedded grains, but there are some of a pink and light red shade, and others of light and dark grey. There are a few pebbles of hälleflinta, one of decomposed rhyolite, and another of quartz-felsite. A pebble of white and several of pink orthoclase showing the cleavage planes. Some indurated angular bits of red clay occur in the basement bed at Flaybrick, but few grits or sandstones have been found. The liver-coloured quartzite has not been seen in any of the localities examined. The largest pebbles found were two inches in length, and they are rare. Small bits and rounded lumps of red and grey marl are very common about the base of the Keuper.

It is remarkable that not a single pebble of the Carboniferous Limestone has been found in either the Bunter or Keuper, from which it may be inferred that the formation was not exposed at the surface during Triassic times. There is evidence that the Cefn-y-Fedw Sandstone, Millstone Grit and Coal-measures were exposed

[1] An Upper Silurian fossil, *Platyschisma*, was found at Eastham.

[2] A similar pebble in exactly the same condition was found in the Keuper at Wallasey.

to denudation during the deposition of the Bunter, as some of the angular fragments of grit and sandstone seem to have been derived from those formations.

The pebbles of the Keuper are similar to those of the Bunter formation, but the number and variety are much less. They do not seem to have been derived from the Bunter, and it is not likely that it was exposed to denudation at the time, so that the probability is that they came from the same source when the supply had nearly dwindled away and was almost limited to those of light-coloured quartzites.

A typical collection of the pebbles, including those from both the Bunter and the Keuper, was sent to Prof. Bonney who minutely examined and kindly sent me the following report thereon :—

"Many of the hard quartzites and quartzose rock (hälleflintas, grits of more than one type—sometimes felspathic) are identical with those which we find in Staffordshire. The igneous rocks (felstones chiefly) are less well preserved and seemingly less numerous, but I think I may say that they present a general resemblance to some of those found in that district. I only observe one piece which resembles 'Torridon sandstone,' and it is so small that I should not like, without microscopical examination, to assert positively that it might not be a fine-grained granite. One of the peculiarities of this grit found in Staffordshire is the difficulty which not unfrequently occurs in distinguishing it macroscopically from granite. But I have no hesitation in saying that your specimens, on the whole, appear to have been derived from the same sources as those we find in the Staffordshire district, only they are smaller and perhaps not quite so well rounded—clearly the Liverpool region was out of the course of the strongest currents.

"At first sight it seems strange that the Bunter in the Cheshire-Lancashire region should be thicker, but of finer material than in the Central Midland district. But it seems to be quite possible that, in the case of strata of fluviatile origin, the deposits, though of coarser material, may be thinner in the line of the stronger currents, because these deposits may be less continuous—just as a river keeps open its channel while raising the land on either side. If we assume a southern origin for the pebbles, we still have the difficulty of the greater thickness of the beds further from the source. One thing cannot be overlooked in speculations, viz. that quartzite pebbles, identical with those in Staffordshire, occur plentifully in the Upper Palæozoics of Southern Scotland. Similar felstones occur, but I can say no more because, when last I saw these Scotch Pebble-beds, I was not paying any particular attention to the matter."

Prof. E. Hull, F.R.S., some years ago, was of opinion that the quartzite pebbles of the Bunter were derived from those of the Old Red Conglomerate of Scotland, and the denuded tracts bordering the German Ocean.[1] More recently, Prof. T. G. Bonney, F.R.S., attributed their source to the quartzite of Ross-shire about Loch Maree, and minutely described the varieties that occur in that

[1] "Triassic and Permian of the Midland Counties," p. 60 (1869).

district, and concluded that they were exactly alike, while they differ from any English rock. He supposes that the Bunter beds of Central and Northern England may represent "the deltas of two great streams descending respectively from the north-west and the north-east, and receiving tributaries from land on either side."[1] Both Prof. Hull and Prof. Bonney agreed as to the origin of the pebbles, and that some may have been embedded in the Old Red Conglomerate, and ultimately in the Triassic sandstone. Indeed, Prof. Hull surmised that they "must have undergone a process of trituration during more than one geological period, else they would not be so invariably bereft of all angularity."

Mr. W. J. Harrison, F.G.S., ascribes the source of the quartzite pebbles in the Midland Counties to the old Palæozoic ridge in Central England, the short distance of which may account for the great number and variety of the pebbles found there.[2] Prof. Bonney, however, states that he has identified two different quartzites there, and that the Ross-shire quartzite is one of them. In 1883 Prof. Hull announced that he had abandoned the view of the North British origin of the pebbles in favour of that proposed by Mr. Harrison, and states that:—"At the time I suggested the Scottish source, I was freshly and vividly impressed with the resemblance of the reddish or 'liver-coloured' quartzite pebbles to those of the Old Red Conglomerate of the Lesmahago and other districts. But I all along felt the difficulty (on which Mr. Harrison lays just stress) that the number and age of the Bunter pebbles decrease from the Central District of England towards the North-west, which ought not to be the case if they had the origin I attributed to them. Further reflection leads me to think that the objection is fatal to the view either of myself or of Prof. Bonney, notwithstanding the microscopic resemblance which he points out to the quartzites of the Highland rocks."[3]

Mr. A. Strahan, F.G.S., is of opinion that the Bunter Sandstone "was distributed by strong currents flowing between Central England and Wales from the South, as the increasing abundance of pebbles in this direction indicates." If such were the case, the Bunter would appear to have been a delta deposit, the production of a river draining the lost Triassic lands.[4]

Conditions of Deposition.

The Permian, Bunter and Keuper formations in the country around Liverpool seem to have been deposited under somewhat similar conditions, and consist of beds of sandstone associated with frequent conglomerates, breccias, shales and marls. Many opinions have been expressed as to the relative conditions under which the formations were deposited, but that there was a gradual change from an open sea in the Permian to a contracted estuary or lake in the

[1] Geol. Mag. Dec. II. Vol. VII. p. 404 (1880), and Vol. X. p. 199 (1883).
[2] Proc. Birmingham Phil. Soc. vol. iii. p. 157 (1882).
[3] "Pebbles in the Bunter Sandstone," Geol. Mag. Dec. II. Vol. X. p. 285 (1883).
[4] "Geology of Cheshire," Journ. Iron and Steel Inst. p. 352 (1884).

Bunter and Keuper, and finally to a great salt lagoon in the age of the Red Marl, expresses the idea generally entertained. The Permian formation was evidently formed during and just after the upheaval of the Coal-measures, and the Trias seems to have originally covered them continuously over South-West Lancashire as it does now about Liverpool. Although the Permian has not been satisfactorily determined in the district, the marine character of the formation is evident from the fossils found at Bedford Leigh twenty miles to the east, and at Collyhurst near Manchester, though they seem stunted in growth as if they had lived in brackish water.

The Bunter formation is usually supposed to have been deposited in lakes or land-locked seas; but in the absence of the remains of marine organisms, it is certain that it was not formed in the open sea, and it is difficult to suppose it had any direct communication with it. It seems more probable that it was deposited along the course and formed "the deltas of two large streams, descending respectively from the north-west and north-east, and receiving tributaries from land on either side," as suggested by Prof. Bonney. These streams brought down such an enormous quantity of shifting sand that there was little chance of a plant, shell, or other organism being preserved in the sandstone. The source of the material, however, must have changed during the flow of these supposed Triassic rivers, for there was an alternation in the character of the sediment; firstly, fine-grained sand containing a great proportion of large rounded grains; secondly, sand with quartz and quartzite pebbles; thirdly, a fine-grained sand again; and sand and pebbles again finally appeared in the Keuper. It seems doubtful whether the pebbles came from the north of Scotland or from the centre of England, and consequently it is equally uncertain as to the origin of the enormous deposit of sandstone 2350 feet in thickness. The pebbles are said to be most numerous in Staffordshire, and decrease towards the north of Cheshire and Lancashire; but this seems rather doubtful, for the thickness of the Bunter becomes much greater in that direction and the pebbles more scattered. If the sand and pebbles came from the Midland counties, it is evident that the sand would be carried the furthest, that the pebbles might be gradually left behind, and that few would reach Liverpool. They may, however, have come from Scotland, down what is now the North Channel—a conclusion which seems probable from the great variety of the quartzites. Pebbles and angular fragments of Carboniferous rocks are common and cannot have come any great distance, and it seems probable that much of the sand came from the same source.

The rounded seed-like grains, like blown sand, have been suggested as indicative of desolate wastes, though this would only apply to the early part of the Bunter, and nothing is really known of the condition of the land bounding the supposed Triassic river, or of the source of the sand. The large smooth grains supposed to have been rounded by the wind are just as likely to have been worn by water, on account of their large size.

The Keuper formation consists of beds of sandstone and marl, and the lower part is sometimes so like the Pebble-beds of the Bunter that it is difficult to distinguish one from the other in the absence of an extended section, showing the relative position of the formations.

The Keuper has fewer pebbles, but thicker beds of shale and marl. The general opinion is that it was deposited in a series of lakes, for no fossils indicating marine conditions have been found, and locally only a few land-plants at Flaybrick and Storeton. There were shores or banks of sand and clay, and the occurrence of ripple-marks, rain-marks, sun-cracks, worm-tracks, and foot-prints indicate changes that might be expected in such situations.

In the Red Marl there is abundant evidence of a salt-lake or lagoon, and the continuous evaporation is obvious from the thousands of pseudomorphic crystals of chloride of sodium that cover the surfaces of shaly beds in the lower portion, while in Central Cheshire thick beds of rock-salt afford evidence of the entrance of sea-water and the subsequent precipitation of the salt. These conditions must have continued for a long period, and it is quite possible that the surrounding country may have been of the desert character that some geologists suppose, though there seems very little to support such a conclusion.

The whole of the Triassic strata were deposited in a subsiding area, but there is no reason to suppose that the water was deep, for the frequent presence of current-bedding indicates shallow-water conditions. It may be remarkable that subsidence should accompany deposition, but if there were no subsidence it is difficult to conceive how deposits of great thickness could be formed in lakes or near the land, for the sediment would be spread further out over the shallow sea-bottom. Dr. C. Ricketts, F.G.S., is of opinion that the increasing weight of the sediment is the cause of the subsidence, but it is just as easy to suppose that where a great thickness of strata occurs, it is in consequence of a long-continued subsidence from some other cause which rendered the great accumulation possible.

IV.—On the Nature and Origin of the Banded Structure in the Schists and other Rocks of the Lizard District.

By Alexander Somervail, Esq.

Introduction.

IN my last communication, "On the Schists of the Lizard District," published in this Magazine for April, which was meant as preparatory for the present paper, my object was to show that the rocks known as the "talco-micaceous," "hornblendic," and "granulitic" groups were of true igneous origin, also plutonic? and had been formed out of a common, but complex magma, and that all of these groups were made up of rocks differing widely from the types of each of them, which in some instances were seemingly due to differences in the rate of cooling, and to chemical affinity; and yet again in other instances to subsequent mechanical movements and pressure during or after consolidation.

Although I provisionally cancelled one of these three groups, the "talco-micaceous," my doing so, as I then stated, would not materially affect the reasoning in that paper, neither will it do so in the present, even if I should be wrong on this point.

The gist of some of my remarks was also meant as introductory to an attempt in the present paper to show that the origin of the banded structure pervading certain of these Lizard rocks might be explained on the ground of segregation, before or during the cooling of the common magma out of which they seemingly had been formed. The fact alone of this magma giving rise to such a diversity of rocks which, although in certain parts of the field isolated from each other, are yet in other parts not only associated and blended together in a somewhat massive way, but in other districts are mingled with each other on a much smaller scale, and with a greater degree of symmetry, so as to pass by easy transition into what is properly termed the banded structure. These facts alone of themselves seem to supply an intelligible basis, or starting-point, for an explanation of this phenomenon—of course confining the term "banded" to those more strictly symmetrical portions of this structure now to be described.

I. Nature of the Banded Structure.

Although this paper is principally confined to the banded structure in the rocks included in the triple or double group of schists and rocks, it may yet embrace all the other rocks of the area, as all of these are more or less banded in one form or another, and the same explanation seems to me to serve for the whole, in the wide and proper sense of the term.

In the double group of schists (and rocks), viz. the "granulitic" and "hornblendic" (between which I have divided the talco-micaceous) are rocks with a wide variation in their banded structures, especially in the granulitic group. In this group it assumes many different forms, ranging from well-defined banding of a more or less regular and persistent horizontal type, to highly irregular bands thinning and swelling out again. At other times the bands are lenticular and run in an oblique direction, and even the materials which form the banding in the base of the rock are sometimes found in isolated patches without any visible connection between them. General McMahon has given a very succinct description of the banding in this group which is as follows: "The rocks of this group are usually spoken of as a banded group, and appearances often support the idea that the quasi-banding is a regular banding parallel to the bedding. When the eye of the observer becomes accustomed to these rocks, however, the banding is seen to be extremely irregular in character. Not only do some of the bands dwindle into strings and die out in the direction of their length, but they inosculate, bifurcate, and entangle themselves into a complicated network of meshes, and they swell in places into broad lacunæ, which, in their turn, throw off fine veins in all directions. Even where these bands are apparently most regular, they will often be found, when followed up, to behave like injections."

My own observations on the nature of the banding I shall now give from a few typical localities, copied from notes as I made them on the spot.

Kennack.—The banded granulitic rocks here consist of a dark basic, or diorite portion, and an acid or granitic one which greatly predominates, varying much in texture and composition, ranging in colour through pinkish-white or grey, to pale red, dark red, and brown. Sometimes these acid or felspathic bands are themselves banded with paler and darker portions of their own composition, thus forming a distinct inter-banding of their own. Sometimes the lines of demarkation between the diorite and granitic bands are of the most perfect nature, but this is not always so, as they frequently pass over into each other by the finest gradations. Besides the intermingling of both of these rocks in the dykes cutting the serpentine of the cliff here, I have noted the fourth dyke west from Kennack as exhibiting a good example of banding in a dyke. The first dyke is also a good instance.

Caerleon and Little Coves.—In both of these coves banded granulitic rocks occur. The most notable feature is at Little Cove, where there is a type of the granulitic not of a very granitic texture, of a reddish colour, rather slightly and confusedly banded, not by dark diorite bands, but by paler and darker shades of red of similar composition to its base. South of Caerleon Cove there are pale felspathic varieties banded with still paler bands of felspar. Both of these varieties occur elsewhere.

Kildown Cove.—Here there are great masses of reddish granulitic rock without any banding whatever, which, however, at some distance off becomes dioritic and banded in the usual way. Here is the rudely circular mass of rock already referred to,[1] made up of the concentric layers of diorite and granulitic, with the latter for its centre.

Flag-staff Quarry, Kildown Point.—The banded structure can here be studied in many of its varieties. The banding in places is of a regular and persistent character, fining down to alternate parallel lines of dioritic and granitic minerals as thin as a sheet of paper, or in broader bands composed of hornblende and felspar mingled together. Highly irregular and lenticular banding also occurs, and in some of the diorite bands are small elliptical masses of the granitic portion, quite isolated from each other. At the top of the quarry where these rocks may be seen (seemingly) cutting through the serpentine, the banded structure is still traceable, but on a smaller scale, and much more confused, the mass of the rock also being modified from its contact with the serpentine.

The Balk.—Here the banded "granulitic" rocks are in great force, consisting principally of the acid and felspathic type, the dioritic portions being very subordinate in comparison to the other. These quartzo-felspathic and granitic rocks are highly banded, not so much with bands of diorite as with portions of their own composition of various textures and colours, according as they consist of felspar

[1] Geol. Mag. Vol. VII. p. 166 (1890).

more or less pure, or mixed with quartz, more or less granitic; the paler shades consisting of the former, the darker of the latter.

Trelease Moor.—The rocks here, which I referred to in my last paper as rising through the serpentine, and as formed of several distinct varieties of rock, ranging between the dioritic and granitic types, I have found in a recent visit, also, to be most distinctly banded, the granulitic bands passing gradually into the more basic portion of the rock.

Although the banded structure exists in the granulitic rocks on the south coast, near the Lizard Head, and in the outlying reefs, and at the Yellow Carn, also on the west coast at George's Cove, yet it presents no special features beyond what has already been noted in the foregoing localities.

In the "hornblende" group the banding is of a much less complex character, the bands of whatever minerals they may be composed having as a rule a linear arrangement. They generally consist of alternations of felspar and hornblende, the latter more pure and granular or crystalline than the base of the rock, the former also differing much in its exemption from other minerals, and likewise in its colours. The felspar bands are not always uniform and parallel, but frequently occur in lenticular patches, and display other irregularities. In thickness they vary from the thinness of a sheet of paper up to bands of a couple of feet or more as at George's Cove. There are also numerous bands of epidote, but they are only to be regarded as an alteration product of the hornblende. Besides the parallel banding in the hornblende group there is another type of less regular banding, gradually becoming more so until the arrangement of the bands are lenticular and the rock in appearance like a well-foliated gneiss.

These gneissose rocks can be studied at the base of the old Lizard Head, and the outlying rocks; also, in those of the Dranna rocks which lie immediately off Porthkerris Point, east of Porthallow.[1] Others of a similar nature have been described by Mr. Howard Fox, on the fore-shore south of Ogo Dour Cove.[2]

II. Origin of the Banded Structure.

It is a remarkable fact that all the great distinctive varieties of rock in the Lizard district exhibit more or less of a banded structure. As is well known, it is present in the gabbro, and even the serpentine is not free from it.[3] A good example of very distinct banding may be seen in the green serpentine of Kildown Cove, and I have noted a similar banding in other localities, over and above the distinct thin layers, or bands of nearly pure hornblende which traverse, even, the true serpentine as at Gue Graze.

[1] The gneissic rocks from both of these areas were shown me by Mr. Howard Fox, F.G.S. In the latter locality I would not have suspected them to occur.

[2] Junction of the Hornblende Schist, etc., Trans. Roy. Geol. Soc. of Cornwall, 1889, vol. xi. part iv. p. 213.

[3] *Vide* paper by Mr. Rutley, Trans. Roy. Geol. Soc. Corn. vol. ix. part 4, 1889, pp. 239–241.

The origin of the banded structure in the "granulitic" and "hornblende" group of rocks in this district has been accounted for in three separate ways by sedimentation, deformation, and by injection.

Sedimentation.—This explanation was very naturally and consistently given by Prof. Bonney on the ground of the rocks being thought by him to be of sedimentary origin. There are, however, certain arrangements in the banded structure of the "granulitic" group which no false bedding could produce, or even simulate. These arrangements of structure I have already given as quoted from General McMahon, and I have myself also noted other appearances such as the numerous fine thread-like processes and broader ones, which cross at various angles from the one band to the other.

If, on the other hand, these rocks are of igneous origin—as I believe them to be—then we must seek for some other cause to explain their banding, even allowing that some of them were originally ashes, altered and deformed by subsequent dynamical causes.

Deformation.—Mr. J. J. H. Teall, M.A., F.R.S., F.G.S., has advanced this theory and has applied it both by observation and experiment in a clear and able manner. He regards a large portion of the rocks at least forming the 'granulitic' group as a complex of igneous rocks partly dioritic and granitic, deformed by dynamic causes, during, or subsequent to their consolidation. This theory (if I mistake not) not only pre-supposes, but points to the existence of heterogeneous masses of these rocks in the field which were the raw materials out of which the banded structure was wrought by subsequent dynamic agencies, which kneaded them more completely together, and produced the secondary results of banding as now exhibited. If this theory is confined to the mere mechanical movement of the rocks without the aid of their partial re-fusion and the consequent effect of chemical agency, it seems to me very hard to explain much of the phenomena presented by the banding as we see it in the field. The subsequent movements might, and I believe do account for much of the eccentricities exhibited by the course of the bands, such as the flexures and zig-zag features occasionally observed, along with other signs of deformation, which has modified but not produced this structure. This theory also seems to account for the quasi-banding in portions of the "hornblende" group, such as the thin deposits of felspar, epidote, etc., developed between the cleavage-planes of the schistose varieties of these rocks, but, to account for the normal or true banding when it does occur, it seems almost powerless.

The principal objections to this theory presenting themselves to my own mind, as far as the "granulitic group" is concerned, are as follows:—

1. The seeming inability of deformation to produce out of an igneous complex the symmetry frequently prevailing in the banded structure. This symmetry consists of the very parallel arrangement of the various bands exhibited in some localities; one band of diorite

and another of granulitic materials alternating with each other, often with much uniformity, in their respective thicknesses, and this too continued over considerable areas.

2. This theory does not explain the frequent transition of these bands into each other, which, although comparatively distinct and well-defined from each other in some areas, and portions of the same mass of rock, are nevertheless, in others, marked by a passage of their mineral constituents.

3. The theory does not explain the banding—most frequently parallel—in those masses of nearly homogeneous granulitic rocks, where the banding is entirely made up of the slightly varying quartzo-felspathic mineral constituents which form them, and not of the widely contrasted bands of dioritic and granulitic minerals; these rocks not coming under what is designated as an igneous complex.

Injection.—This theory has been advanced by General McMahon more particularly to account for the banding in the "granulitic" group, a group, as already stated, considered by him to be made up of volcanic ashes and lavas, into which have been intruded diorites and subsequently other porphyritic diorites, and by granites still later, each in its turn injecting the other. It is, however, to the last of these, the injection of the granite, that, according to General McMahon, the banding is due, or mainly due, at least it is made the prominent factor in his explanation. He remarks that, "the process of injection was doubtless aided by the partial plasticity of the dioritic rocks—a plasticity induced probably by the neighbourhood of igneous masses, for it seems to have been local in its development. It would also have been aided in the case of consolidated ash-beds—especially in submarine ash-beds—by the planes of sedimentation, and in the case of diorite intruded as sheets by the foliation developed in a direction parallel to the bedding. The existence of such planes of weakness would explain why the injected granite displayed a tendency to follow lines parallel to the bedding, and in doing so produced the superficial appearance of banding."

This explanation of General McMahon's certainly much better meets the difficulty or objection just urged against Mr. Teall's views, which afford no explanation of the symmetry of the banding, to which attention was drawn; indeed, according to the theory of the latter (if I understand it aright), it would be entirely destructive of this parallel or symmetrical structure, and not the cause of it.

As a whole, however, the "injection" theory seems to me to fail even in the one direction in which it has been applied, while it offers no adequate explanation of the banded structure in a general sense.

To whatever cause, then, the banded structure may ultimately be assigned, I think it sufficiently clear that all of these three modes of explanation completely fail when applied to these Lizard rocks. First, the sedimentary, because it is at once negatived by the igneous origin of the rocks in question, no tuffs as yet having been recognized. Second, the deformation theory, because it never could produce the linear arrangement or parallel structure as we find it

in both (what I may term) the heterogeneous and homogeneous granulitic masses. Although I must admit such an arrangement can (to a certain extent) be produced by pressure exerted on clays, as described by Mr. Teall, by artificial means, but not to meet all the facts as presented in the field. Third, the injection theory, because even in the solitary instance in which it can be applied, the parallel bands of diorite and granite show no decided signs of intrusion into each other.

III. Due to Segregation.

The only theory which to my mind seems to explain the banded structure in these Lizard rocks is segregation. (By this term I mean the separation of the unlike, and the union of like mineral constituents taking place during their cooling.) It seems to me to satisfy all the different aspects of their banded structure; and these, as already stated, present a considerable variety of more or less distinct types, some of them so palpably due to this cause that in my field notes, made during a number of years, I have again and again the word "segregation" written against the description of these banded rocks.

If I can succeed in showing—as attempted in my former paper—that the varieties of dioritic and granulitic rocks were differentiated out of a common magma, then it would seem to follow that such a separation on a smaller and less perfect scale, under conditions to which the term segregation might be more properly applied, would produce such a result as the banding in all its varied aspects.

The proofs already given of such a separation need not here be again recapitulated; but to those proofs might be added the fact mentioned by Mr. Howard Fox and myself in a joint paper[1] that the hornblendic and felspathic lines circle round the porphyritic crystals of felspar in the dark or dioritic bands of the granulitic series. These lines must have so arranged themselves after the cooling of the felspar forming these crystals, which, besides being an excellent proof of the segregation of these mineral constituents from the common magma, is also a convincing one of the igneous origin, and, let me add, also of the plutonic origin of these rocks.

Besides these facts, I have already drawn attention to others bearing out the important part that segregation has played in these Lizard rocks, in my short paper "On the Greenstone and Associated Rocks of the Manacle Point,"[2] which seems to afford the only possible explanation of that area.

Still further, in my last communication, already referred to (p. 166), I drew attention to a concretionary mass of granulitic rock at Kildown Cove composed of concentric layers of dioritic and granulitic minerals, which is simply the banded structure in a rudely circular form produced by segregation. This mass is certainly not the product of an original and an intruding member, but clearly the

[1] Geol. Mag. Dec. III. Vol. V. p. 77.
[2] Geol. Mag. Dec. III. Vol. VI. p. 425.

product of one cooling mass arranging and separating itself into distinct layers as before described.

An excellent instance of what I regard as segregation bands in the hornblende group may be studied in a large boulder resting in the small cove immediately to the west of Lower Balk Serpentine Quarry. This mass presents a parallel banded structure made up as follows. There are broad and narrow bands of nearly pure pale-coloured felspar alternating with thinner bands of nearly pure dark hornblende more crystalline than the base of the rock. What looks at a little distance like other broad bands of the pale felspar are found on closer inspection to be made up of very thin deposits of that mineral set closely together, some of which are not persistent for a small space, but are again continued without any interruption in their parallel course. At intervals along with these are bands of varying width of the ordinary hornblende, some of which are highly porphyritic, the long axis of the felspar crystals being parallel to each other, and in the direction of the bands themselves, as if that mineral in places was not sufficiently abundant to be drawn out into the form of continuous bands.

All these varieties of banding in this one mass of the hornblende series was most convincing to my mind that the felspar had arranged itself, as also the more crystalline hornblende, by segregation during cooling.

Some of the difficulties in the way of an explanation of the banded structure, pointed out by General McMahon, such as where in some instances the bands "inosculate, bifurcate and entangle themselves into a complicated network of meshes," and in other cases given by myself where filaments or thread-like processes, and broader strings, cross at various angles from one band to another, are all readily enough explained on the grounds of segregation while the mass of the rock was in a molten or plastic state, admitting of the various movements of its several constituents.

The banded structures in the gabbro and serpentine are equally well accounted for by segregation, while on the ground of deformation it is barely possible, more especially in the latter rock.

IV. Concluding Remarks.

Although we are quite unaided, as far as I am aware, by the results of any experiments such as might be made by melting the basic and acid rocks together, as, for example, diorite and granite, and allowing the molten magma slowly to cool again, in order to ascertain what arrangement its several constituents might take, effected no doubt by their different cooling points, chemical affinities, and specific gravities, still, we can infer from reflection, and from certain rocks presented to our observation in the field, that under certain conditions, such as unequal and different rates of cooling of the various mineral constituents, abnormal forms of crystallization would arise. That these and other conditions would produce various structures such as the separation by segregation of the various minerals in masses of more or less definite arrangement

is quite apparent. The parallel or banded structure, a priori, would be as likely a one as any.

Dr. Sterry Hunt, in contributions to the American Journal of Science for March and July, 1864, gives several instances of banding in rocks which, according to his own descriptions, seem to me to be due to segregation. Describing a granitoid dolerite at Mount Royal, he says it consists of "Mixtures of augite with felspar in parts of which the felspar predominates, giving rise to a light greyish rock. Portions of this are sometimes found limited on either side by bands of nearly pure black pyroxenite, giving at first sight an aspect of stratification. The bands of these two varieties are found curiously contorted and interrupted, and seem to have resulted from movements in a heterogeneous pasty mass, which have effected a partial blending of an augitic magma with another more felspathic in its nature." In another communication by the same author to the Boston Society of Natural History, January 7th, 1874, he describes an eruptive diorite from Lambertville, New Jersey, "which is conspicuously marked by light and dark bands due to the alternate predominance of one or the other of the constituent minerals." The same author, again, in his "Chemical and Geological Essays" (Granites and Granitic Vein-stones), gives instances of a banded structure in granites, and granitic dykes. All of which instances can only be explained I think by segregation.

While regarding what I would term the normal or true banding as of segregation origin, I do not wish to overlook what I myself believe to be a fact, viz. that certain types of the banding in some of these Lizard rocks are due to subsequent causes, the product of severe mechanical pressure or crushing. Such banding, or perhaps more properly speaking, foliated structure, as occurs among some of the hornblende schists, and also in certain portions of the gabbro, I think may be due to this cause; but, after all, this is still the product of segregation, secondary segregation we may call it, produced by the heat being sufficiently great to admit of partial fusion, and of certain of the minerals in a greater or lesser degree to re-arrange themselves. Under these circumstances secondary segregation would seem to me to give rise much more readily to certain forms of lenticular foliated structure, rather than to the parallel banded structure proper, which I think is due to original, or primary segregation, while the rock was in a complete state of fusion.

There are other forms of what might be spoken of as banding, which, however, are only pseudo-bands which seem merely due to the development of secondary or alteration products between the planes of cleavage, such as are frequently met with in the hornblende schists. These and certain other similar types more properly fall under the term cleavage foliation, rather than under that of banding.

V.—Suggestions on Sites for Coal-search in the South East of England.[1]

By W. Whitaker, B.A., F.R.S., F.G.S.

THE general question of the rise of older rocks beneath the Cretaceous beds of south-eastern England is now so familiar to geologists that there is no need to discuss it here: it is enough to note that the Secondary beds (beneath the Gault) thin northward, for many miles, from the axis of the Weald. The practical application of our knowledge of the subject is however in its infancy, and our knowledge stops short at the Wealden axis; for we do not know what happens south of it.

Having regard to the great expense of making the deep trial-borings that would be needed in the search for coal in this district, it is clearly well, as far as possible, to select sites where a good amount of the work has been already done. The object of this note is to point out that there are such sites, and that they are favourably placed for the search.

These sites will be noticed beginning at the south-east, near the only place where coal has yet been proved in the large tract in question, and working thence westward and northward.

1. *Saint Margarets.* About 4½ miles north-eastward of the boring that has shown the presence of coal underground near Dover, is a trial-boring, made by the former Channel Tunnel Co., which reaches the Gault at the depth of 548 feet. Presuming that the beds beneath are the same as at Dover, a further depth of say about 900 feet (in the absence of precise information) would be needed to show whether coal is present or not; but as, on the southern side of the London Basin, the thinning of the beds between the Gault and the older rocks is in a northerly direction, we should expect that there would be less of these beds at St. Margarets than at Dover.

It is remarkable that whilst at the Dover trial-boring no Wealden beds were found, another boring, at the Convict Prison, a little to the north-east, seems to have reached beds of that age, at the depth of 849 feet. A continuation of this boring would of course be of interest, though the site is near that of the successful trial.

2. *Chartham.* Some three miles south-westward of Canterbury another boring has reached the same horizon, having touched the Gault at the depth of 735 feet, and here probably the beds between the Gault and the older rocks would be much thinner than at Dover.

3. *Chatham.* A boring at the Dockyard has given us much more information than either of the above, for it has reached the bottom of the Cretaceous Series at the depth of 943 feet, and has been carried 22 feet in Oxford Clay. Seeing that at Dover all the three divisions of the Jurassic Series are represented, and that at Chatham the whole of the Upper Jurassics and part of the Middle Jurassics are absent,

[1] A paper read to the Brit. Assoc. at Leeds, and printed in the *Yorkshire Post* (and other newspapers), and in the *Brighton Magazine* (October, 1890). Some slight additions and corrections are now made.

it is clear that at the latter place we have much less of that series to contend with than at the former. Moreover, it is likely that the rest of the Middle and the Lower Jurassics will share in the thinning and will be of less thickness than at Dover. It seems to me that the Chatham boring should certainly be continued, as a deepening of a few hundred feet would probably show which of the older rocks there comes beneath the Secondaries. Moreover, the site and the land around belong to Government, as also does a neighbouring boring, at Chattenden, which has reached the base of the Gault at the depth of 1162 feet; so that a successful result would benefit the nation.

4. *Shoreham* (Kent). A well here, in the valley of the Darent, has gone 26 feet into the Lower Greensand, with a total depth of 475 feet, comparatively little Chalk being present.

In Surrey, at Caterham and at East Horsley, are two borings, to the same depth, 874 feet; but whilst the former has been carried a little way into the Lower Greensand, the latter has done little more than reach the Gault. I am inclined, for the present, to pass these by, and to turn to the northern side of the London Basin, from west to east.

5. *Bushey* (Herts). A boring here has been taken nine feet into the Gault, at the depth of 700 feet; but, being at a waterworks (as also is that at Caterham), it probably could not be touched. The knowledge of what would be found here a few hundred feet further down would be very useful, and possibly less than 200 feet would reach the base of the Secondaries.

6. *Loughton* (Essex). Here a boring has found water, apparently at the base of the Gault, at the depth of little less than 1100 feet, from which one infers that Lower Greensand may have been touched. It would be well, however, for inference to be supplanted by knowledge.

We do not know what beds were found in the bottom part of another Essex boring, at Saffron Walden, which reached to a depth of a little more than 1000 feet. By inference they are Jurassic, the earlier accounts having given much too great a thickness to the Chalk. Here again inference is not enough.

7. *Coombs*, near Stowmarket (Suffolk). A boring, 895 feet deep, has here pierced 11 feet of Gault. Judging from what was found at Harwich, some 20 miles S.E., it is not likely that a much greater depth would be needed to reach some member of the older rocks, and, as at Harwich the bottom-rock is Lower Carboniferous, it is to be hoped that further work may be done in that neighbourhood.

The more northerly boring at Norwich is too far from our base (of knowledge already gained), and that at Holkham, near Wells, at the northern edge of Norfolk, is still more so, besides being no very great distance from the outcrop of thick Jurassic beds.

Further examination of our great stores of well-sections would perhaps result in the selection of many other sites at which much of the work is already done; but in the above remarks only such borings as have been carried beneath the Chalk are referred to.

A full account of the history and literature of the question of the underground range of the older rocks in the South East of England, especially as regards the possible occurrence of Coal Measures, has been given in lately published Geological Survey Memoir, "The Geology of London and of Part of the Thames Valley."

VI.—On Pre-Cambrian Rocks Occurring as Fragments in the Cambrian Conglomerates in Britain.

By Henry Hicks, M.D., F.R.S., F.G.S.

(Read at British Association, 1890.)

OF late years the Cambrian Conglomerates have received a considerable amount of attention, as it has been shown that much information concerning the nature and condition of the Pre-Cambrian rocks can be obtained by the careful examination of the materials composing the conglomerates in different areas. It is evident that rocks similar to the rolled fragments in the Conglomerates must have been present in pre-Cambrian times to yield these fragments, and if in certain areas special rocks occur abundantly or otherwise, the characters of the pre-Cambrian rocks in these areas may be to a great extent determined. The Cambrian Conglomerates in Wales and Shropshire have been very carefully examined by Prof. Hughes, Dr. Callaway, and myself, and the materials collected have been submitted to Prof. Bonney and Mr. T. Davies for microscopical examination. These eminent petrologists have from time to time described the results of their examinations and have shown most conclusively that certain fragments which occur in the Conglomerates are in the minutest particulars identical with rocks which have been claimed by us, in the areas in which the Conglomerates occur, as being of pre-Cambrian age. In some areas the Conglomerates have been found to be composed almost entirely of materials from rocks, which can clearly be shown to underlie them, and the special characters recognizable in the rocks below are found in the rolled fragments in the Conglomerates which rest unconformably upon them. I have endeavoured to indicate by a table the contents of the basal Cambrian Conglomerates in Britain in several of the areas where it has been claimed that pre-Cambrian rocks are now exposed, and an analysis of this table is in many ways very suggestive. It is found that certain rocks occur in each of the areas, whilst others are limited to those districts where special rocks are known to characterize the pre-Cambrian series. In the first column I have given the rocks which I have collected in Pembrokeshire, and these are, in the main, very similar to those which have been collected in N. Wales and Shropshire. Those mentioned from Ross and Sutherland have either been collected by myself, or are mentioned in papers by the officers of the Geological Survey. The Cambrian Conglomerates near St. David's, Pembrokeshire, have perhaps received more attention than those of any other area, and the notes furnished by Prof. Bonney and Mr. T. Davies prove in the

TABLE SHOWING THE ROCKS WHICH HAVE BEEN FOUND IN THE CAMBRIAN CONGLOMERATES IN DIFFERENT AREAS.

Rocks.	Pembroke-shire.	Merioneth-shire.	Carnarvon-shire.	Anglesey.	Shropshire.	Ross-shire.	Sutherland-shire.
Granitoid (granite, pegmatite, etc.)	x	x	x	x	x	x	x
Quartz porphyry ...	x	...	x	x	x		
Felsite	x	x	x	x	x		
Rhyolite, dacite and andesite	x	x	x	x	x		
Diorite and syenite ...	...	...	...	...	...	x	x
Diabase and basalt ...	x	x	x	x	x	x	x
Gneiss	...	...	...	x	x	x	x
Sericite-schist	x	x	x	x	x	x	
Chlorite-schist	x	x	...	x	x	x	
Hornblende-schist ...	...	...	...	x	...	x	x
Mica-schist	x	x	x	x	x	x	x
Quartz-schist	x	x	x	x	x	x	x
Volcanic fragmental (acid and basic)	x	x	x	x	x	x	x
Porcellanite	x	x	x	x	x		
Clay-slate	x	x	x	x	x	x	x
Quartzite	x	x	x	x	x	x	x
Sandstones	x	x	x	x	x	x	x
Calcareous	...	...	...	x	...	...	x
Ferruginous	x	x	x	x	x	x	x
Quartz, jasper, etc. ...	x	x	x	x	x	x	x

most conclusive manner that some peculiar granitoid rocks, basic and acid volcanic rocks, schistose rocks, porcellanites, and argillites, similar to those which are found in the pre-Cambrian axis, occur as rolled fragments in the overlying Conglomerates. As these fragments are now, in all important particulars, identical in character with and can be shown to have suffered all the mineralogical changes which the rocks from which they were derived had undergone before they were broken off, it is perfectly evident that not only must there have been a considerable lapse of time, separating the Cambrian from the pre-Cambrian, but also that during that interval the area must have been subjected to very important physical changes. The following places may be mentioned as offering important evidence in support of the above views. At Ramsey Island, and Treffgarn in Pembrokeshire, at Bangor, and near Llanberis and Bethesda in Carnarvonshire, where the Cambrian Conglomerates rest on felsites and old rhyolites, more than three-fourths of the pebbles, which are frequently of very large size, have been derived from the immediately underlying rocks. Near St. David's, and at other places where the conglomerates rest on various altered volcanic tuffs, a large proportion of the pebbles have been derived from those tuffs after they were cleaved and otherwise changed into their present condition. At Porthclais, Chanter's Seat, and Port Melyn near St. David's a large number of the pebbles (mostly of small size)

and the mixture of broken quartz and felspar of which some of the beds are almost entirely composed, could only have been derived from the underlying granitoid rocks (Dimetian). Near Llanfaelog and Llanerchymedd in Anglesey, very large pebbles of the underlying granitoid rocks are abundant in the overlying Cambrian Conglomerates and at Twt Hill, near Carnarvon, the matrix and many of the pebbles must undoubtedly have been derived from the underlying granitoid rocks.

The so-called Torridon conglomerates and sandstones in Ross and Sutherland contain abundant evidences to show that most of the materials were obtained from the rocks upon which they now rest, after the latter had assumed their present condition.

The presence of pebbles of granitoid rocks, quartzites, quartz-schists, etc., in all the areas proves clearly that some granitoid rocks were exposed to denudation on a large scale in many areas, in very early pre-Cambrian times; for materials derived by denudation from the latter rocks must have been formed into quartzites, porcellanites and schists (Arvonian rocks) in early pre-Cambrian times. By subsequent denudation these yielded pebbles to the newer pre-Cambrian rocks (Pebidian) and afterwards to the basal Cambrian conglomerates. I maintain therefore that the pre-Cambrian rocks contain evidences of successive periods of elevation and depression, and probably of volcanic activity, and that the tendency of the evidence is undoubtedly to show that some granitoid rocks, such as those we have classed in Wales under the name Dimetian, are amongst the very oldest of the pre-Cambrian rocks which are now found exposed, and that some quartzites, porcellanites and schists occupy an intermediate position in point of age between these granitoid rocks and the Pebidian series. The pre-Cambrian periods therefore, which I have defined by the terms Dimetian, Arvonian, and Pebidian, are easily recognizable, and seem to have succeeded one another in that order.

In my early papers I stated that the Dimetian granitoid rocks were probably of metamorphic origin. Since then I have been led to change this opinion, and to admit that these peculiar granitoid rocks of early pre-Cambrian age, exposed in several areas in North and South Wales, must have had an igneous origin. There is no evidence to show that there are any rocks of sedimentary origin in Wales which can be classed as belonging to that period. The quartzites, quartz-schists, and porcellanites found in Anglesey and elsewhere were probably derived by denudation from these granitoid rocks, and should be classed, as suggested by me in papers in 1880 and 1881, as belonging to the Arvonian period. Some peculiar acid volcanic rocks found in Carnarvonshire and Pembrokeshire belong also to this period, for fragments of these rocks, in the condition in which they are now found, occur abundantly in association with the pebbles of quartzites, quartz-schists and porcellanites in the Pebidian agglomerates.

REVIEWS.

I.—Les Enchainements du Monde Animal dans les Temps Geologiques. Fossiles Secondaires. By Albert Gaudry. pp. 523. (Paris, 1890.)

THE literature of Palæontology has been marked by a dearth of any satisfactory popular handbooks, answering to the innumerable works by which the study of Zoology has been encouraged and advanced. There have been admirable scientific text-books suited to the student, and any number of volumes discussing the relations of fossils to cosmogonies and fads; but there are very few books such as the present, sufficiently simple to be intelligible to the ordinary reader, and yet commanding the respect due to so well known and distinguished a palæontologist as Prof. Gaudry.

The work commences with a chapter on the divisions of the Mesozoic, with a tabulation of most of the palæontological zones—and in some cases "*zonules*"—of the French deposits. The bulk of the volume is occupied by an account of the various groups of the animal kingdom as developed in the Mesozoic era. These divisions are sketched shortly and simply, and the leading points in their structure and palæontological value well brought out. Thus the great variability of the Foraminifera is illustrated by a number of figures showing how *Oolina* might pass to a *Cristellaria* either through such a series of forms as *Nodosaria* and *Marginularia* on the one hand, or through *Frondicularia* and *Flabellina* on the other.

The author's principal conclusion seems to be that the corollary to the acceptance of evolution is a great simplification of palæontological nomenclature. He points out in the preface that the attempt to give separate specific names to each shade of variation would simply result in the compilation of "catalogues sans limites où l'humaine faiblesse se perdra." He repeatedly asserts that the width of specific range that is regarded as admissible in the members of any group is simply dependent on the amount of work devoted to that group. Many arguments in support of these views are scattered through the descriptive portion of the treatise. As is pointed out in the preface, the work is not a simple text-book of palæontology, but an exposition of these ideas. Nevertheless the short descriptions of the classes, and the extensive series of admirable illustrations, will enable a reader to obtain a good idea of the principal variations in any group. This is a book, moreover, which will well repay perusal by more advanced students, as it is full of most valuable and original suggestions. In fact, the most serious fault to be found with the work is the way in which new ideas are proposed without adequate illustration or discussion. Thus Prof. Gaudry's theory of the origin of the Actiniaria from the Rugosa through the Astreans, Turbinolidæ, and Perforata, is compressed with five illustrations into a page and a quarter. More space might also be devoted to the suggestion that the old naturalists were not so far wrong in allying the Foraminifera with the Mollusca;

the former, says the author, may be derived from the latter by arrest of development, which, however, has affected the soft parts more than the more simply organized shell. Though this hypothesis is advanced "with all reserve," it is so briefly and prettily expressed, that an elementary student might easily be induced to adopt it.

The preceding volume of this work, dealing with the Palæozoic fauna, was issued in 1883; the first part describing the Tertiary Mammalia was published in 1878, and has long since been out of print.

If Prof. Gaudry, instead of merely republishing that book, would prepare a similar volume to the present one, dealing with the whole Tertiary fauna, he would still further add to the feelings of gratitude that must be entertained by all who are interested in the popularization of palæontology.

In conclusion, we cannot speak in too high terms of one who has, like Prof. Gaudry, devoted his life to the exposition and illustration of palæontology, and whose numerous original researches and publications upon the fossil Mammalia of Attica, of Mont Lébéron, and other localities, have won for him the highest scientific reputation.

II.—Researches on Ripple-marks and on Wave-action. By A. R. Hunt, M.A., F.L.S., F.G.S.

GEOLOGISTS have given their attention to the subject of Modern as well as Ancient Sea-beaches, but they have not occupied themselves very much with the present state of the Sea-bottom extending from low-tide mark to 40 or 50 fathoms. Submarine researches are, however, capable of affording much valuable information to geologists, not only on the character of the rocks that may form the sea-bed beneath recent deposits, but also on the nature of the deposits now forming and the influences that affect them. For a number of years Mr. A. R. Hunt, of Torquay, has devoted himself to researches on these subjects, principally along the coast of South Devon, and he has thrown considerable light on the nature of the rocky floor in certain places, from the evidence of a number of trawled blocks.[1] It is, however, to his observations on Ripple-marks and Wave-action that we wish now to direct attention; and as these subjects appeal also to the mathematician, he has sought aid from Sir G. Stokes and Lord Rayleigh. In 1882 he constructed an experimental tank to test his observations on the production of Ripple-marks, and his conclusions are that they are due to wave-currents, and are independent as a rule of tides and tidal currents. The sand-ripples on beaches are made by alternate currents set up by waves, and those laid bare by the fall of the tide may often be distinguished from the Ripple-marks made at greater depths. The shore Ripple-marks are usually imperfect through loss of their sharp ridges. Wave-currents make ripples with equal sides; continuous currents, or continuous currents disturbing wave-currents, make

[1] Notes on the Submarine Geology of the English Channel off the Coast of South Devon, Trans. Devon. Assoc. 1880-89.

ripples with unequal sides. Ripple-marks on shore are better preserved in pools, where they are more or less protected from continuous currents. The direction of Ripple-marks has, however, no necessary relation to the direction of the wind.

The bottom of Torbay, usually smooth, was found to be strongly rippled by swells following a gale, and the author has discussed at some length the depth to which submarine deposits may be disturbed. Evidence is brought forward, from the occurrence of rolled shells, of disturbance of the bed of the sea at depths up to about 38 fathoms; and even at 40 or 50 fathoms, though the Wave-action may be slight, it is not to be disregarded, at any rate in an area subject to oceanic swells and where there is a tidal current. The evidence obtained from a soda-water bottle dredged up from 40 fathoms, showed that the sea-bottom was subject to alternate periods of rest and disturbance. This bottle was found to contain 55 species of shells, which must have been washed in by wave-currents during heavy storms. *Serpulæ* were growing in the neck of the bottle, and they prevented two of the shells (*Pecten opercularis* and *Fusus gracilis*) from being extracted.[1]

Disturbance in shallower water at depths of six fathoms in Torbay is shown by the occurrence on the shore of two species of *Cardium* (*C. aculeatum* and *C. tuberculatum*). Specimens of the former, which were much rolled, had been derived from the sea-bed beyond the six-fathom line where they are known to flourish. Thus different species of Mollusca come to be grouped sometimes separately, sometimes together in deposits of the same age; while by the changes in the supply of mud or sand species locally become extinct, and may be replaced by another species.[2]

Storm waves help to maintain the general level in the soft materials accumulated on the sea-bottom, and level plateaux of limestone rocks may be formed by rock-boring animals eating down the rock to the level of surrounding accumulations. Marine shoals and sandbanks are commonly the joint production of wave-currents and tidal-currents. The neutral wave-currents keep the component parts in motion, whilst cross-tidal-currents accumulate them.

On the subject of the wearing of sand by marine action, evidence is obtained from the Skerries shoal in Start Bay, where grains are present in all stages of rounding, from the jagged fragment of quartz with its angles just showing wear, to the perfectly smoothed and polished spheroid. Some of the grains of sand exhibit a deposit of secondary quartz, and not only has the original grain been worn, but the crystalline encrustation also. The author believes that on sandbanks where tidal and other currents keep in circulation a small volume of sand, the rounding action of the waves is of importance; for, as he remarks, "The misinterpretation of the origin of the constituent grains of a sandstone may result in utter confusion,

[1] On the Formation of Ripplemark, Proc. Royal Soc. vol. xxxiv. pp. 1–18.

[2] See paper "On the Influence of Wave-currents on the Fauna inhabiting Shallow Seas," Journ. Linn. Soc. (Zoology), vol. xviii. pp. 263–274.

to the extent of substituting arid deserts for marine areas, and lengthy rivers for isolated shoals." [1]

The author points out that the fountain-head of all the misunderstanding about waves among practical men has been Scott Russell's error in assuming that oscillating sea-waves are converted into waves of translation on running through shallow water over a shelving bottom.[2] Mr. Hunt's experiments show that oscillating waves, after traversing a gentle gradient, plunge seawards of the water margin; and he maintains that erosion by plunging waves often extends far seaward of low-tide level. Indeed erosion by the wave-currents of the heaviest oscillating waves extends with diminishing intensity to a depth of at least 40 fathoms.[3]

The observations of the author on the combined action of waves and wind-formed currents in removing and accumulating shingle are of considerable interest and importance, affecting as they do our knowledge of the beach-forms of the present day, and of the agents that produce and modify them. H. B. W.

III.—Memoirs of the Geological Survey of New South Wales. Palæontology, No. 4. The Fossil Fishes of the Hawkesbury Series at Gosford. By Arthur Smith Woodward, F.Z.S., F.G.S. 4to. pp. xiii.+55; with ten Plates and two Geological Sections. (Published by Chas. Potter, Sydney, New South Wales, 1890.)

In consequence of the discovery of some fossil fishes in the Hawkesbury Series at Gosford, New South Wales, the fossil collector of the Geological Survey was set to work in the quarry, with the result, that a fine series of nearly four hundred specimens was obtained; and the present memoir is a detailed description of the species by Mr. A. Smith Woodward, of the British Museum (Natural History), Cromwell Road, S.W.

The geological age of the Hawkesbury Series is not satisfactorily settled, although generally considered to belong to the Trias. It was hoped, therefore, that the fortunate discovery of these fishes would throw much light on the stratigraphical position of a very unfossiliferous set of beds, and this hope has not been disappointed.

Some account of the rocks exposed in the Gosford quarry is given in a preliminary note, by Mr. T. W. Edgeworth David, of the New South Wales Geological Survey, who, judging chiefly from boreholes in the district, is of opinion that about 2462 feet of strata intervene between the beds containing the fishes and the Coal-measures. This description is accompanied by a geological section of the quarry, and a vertical section of the beds found in the neighbourhood, showing the position of the "Sandy Shale" and

[1] "The Evidence of the Skerries Shoal on the Wearing of Fine Sands by Waves," Trans. Devon. Assoc. 1887.

[2] On the Action of Waves on Sea-Beaches and Sea-Bottoms, Proc. Royal Dublin Soc. vol. iv. pp. 241-290 (1884).

[3] Denudation and Deposition by the Agency of Sea-Waves, experimentally considered. With Preface: "The Story of a Research." Privately printed, 1889.

"Laminated Mudstone" in which the fishes occur. These two sections are given as full-page plates; but by whatever process they may have been reproduced, they compare very unfavourably with the fine series of plates representing the fossils, and are not in keeping with the other parts of the work. It is to be regretted that these rough-looking plates should have been introduced to the detriment of what is otherwise an admirably executed memoir.

The remains of a small Labyrinthodont have been found in this fish bed, and have already been described by Prof. W. J. Stephens, in the Proceedings of the Linnean Society of New South Wales.

Mr. Smith Woodward's description of the Gosford fishes occupies between fifty and sixty pages, and is illustrated by ten excellent lithographic plates by Messrs. Berjeau and Highley. The greater number of these fishes belong to the *Ganoidei*; but among them there is one specimen, referable to the Cestraciont group of Selachians, which is, however, too imperfect to admit of even generic determination; and there are some others, representing the *Dipnoi*, for which a new genus and species, *Gosfordia truncata*, are established. The Ganoids are represented by nine genera, of which one only, *Apatolepis*, is new; but two others, *Myriolepis* and *Cleithrolepis*, were proposed by Sir Philip de M. Grey Egerton in 1864 for specimens from New South Wales, sent over by the Rev. W. B. Clarke. Each of these genera is represented by one or two species, as are also the following six, namely, *Dictyopyge*, *Belonorhynchus*, *Semionotus*, *Pristisomus*, *Pholidophorus*, and *Peltopleurus*. Altogether fourteen new species of Ganoids are described.

After a detailed description of each genus and species the author institutes a comparison with the genera which have been found in the Trias, Rhætic, and Lower Lias of other parts of the world, and in order to show more clearly the position occupied by the Hawkesbury fishes, the important genera from the above formations are arranged in a tabular form. Attention is called to the absence from the Hawkesbury beds of fishes with well-developed vertebral centra, and the conclusion is drawn, that, so far as can be determined by the fishes, the Hawkesbury beds are homotaxial with the Keuper of Europe, or at latest with the Rhætics.

The description of the Gosford fishes has been very carefully and systematically carried out by Mr. Smith Woodward, and the printing and lithographic plates are all that can be desired. Indeed, with the exception of the geological sections alluded to above, the memoir is worthy of the Geological Survey, by which it is issued, and a credit to the editor, and all concerned in its production. E. T. N.

IV.—Annuaire Géologique Universel. Revue de Géologie et Paléontologie. By Dr. L. Carez and H. Douville. Tome v. Année 1888. (Paris, 1890.)

THE rapid growth in size in the volumes of the "Revue Geologique Annuaire" has been fully continued in that issued for the year 1888. It consists of 1273 pages as against 922 in the preceding volume, while an increase of 700 entries in the bibliographic index

has brought up the number to 3550. The volume is continued on the same plan as its predecessors: it commences with a numbered bibliographic list, in which geology occupies 117 pages, and palæontology 31. The geological part of this is arranged geographically, each section being subdivided stratigraphically. The bulk of the work is occupied by the "Revue," which is treated under three main heads, stratigraphy, topography, and palæontology. Several additions and changes have, as usual, been made in the staff; thus Dr. Trouessart no longer has to review the whole of the Vertebrata and Arthropoda, as Dr. Depéret relieves him of all the Vertebrata but the Mammalia, and MM. Dollfus and Bergeron of the Arthropoda. M. Ch. Brongniart contributes for the first time the article on Insecta. In general geology two new sections have been added, viz. Petrography, by M. U. Le Verrier, and Volcanoes, by Dr. H. Johnston-Lavis. M. Choffat has ceased to review the Jurassic palæontology, but continues in charge of the section on Spain and Portugal. Asia is not this year omitted, as M. de Margerie has contributed a note upon it. The longest sectional review is that on Russia, by Prof. Pavlov, which occupies thirty-three pages; it gives a good idea of the valuable work now being done in that country. The titles of the papers are translated, but the authors' names are transliterated on no definite plan, and this results in many puzzling inconsistencies and anomalies.

The "Annuaire" appears to experience the same difficulty as the "Zoological Record" in getting specialists for all the groups; thus in it some sections have been compiled by men, who, though eminent in their own departments, have no special knowledge of the group they record: in such cases the credit of both works suffers severely.

The English section is admirably done by Dr. Carez: a few misprints are inevitable, as "a visit to *C*hap" (Shap), or the discovery of "pievite" instead of picrite; the author balances a tendency to dock Welsh names, as in "Mynyd Maw," by an unoccasional addition, as in the name of Mr. H. H. Wind*w*ood. It might have been better to refer Gastaldi's letter to Sterry Hunt to the Geological Magazine, where it was published verbatim, rather than to the few line abstract in the Brit. Assoc. Reports. No complaint can, however, be made against the "Annuaire" on the ground of not noticing both places of publication of a work, as they carry the system to an almost unnecessary extent: thus all papers published in the Q.J.G.S. are recorded thrice; in the Journal, in the Abstracts of Proceedings, and in the Geological Magazine where the abstracts are reprinted.

In the case of so valuable a guide to current literature the geologist must feel too grateful to be critical. The undertaking is ambitious: it aims at combining the bibliographic completeness of the English Records with the short abstracts of the Neues Jahrbuch. Hence it is not surprising that there are many points to which objection might be made: thus in the important consideration of promptness of publication, it is beaten by the Zoological Record by some five months;[1] it, however, compensates for this by its greater

[1] It is dated 1889 on the title-page, but the preface is correctly given as 1890.

completeness. Thus a record of the Echinoderms which does not include Cotteau's Eocene Échinides (Pal. Franc.), de Loriol's Crinoides Jurassiques, and Échinides crétacés du Portugal, Pomel's Paléontologie de l'Algerie; nor mentions Seune's discoveries in the Pyrenees, White's in Brazil, or de Loriol's additions to the fauna of Angola, cannot be for a moment compared with M. Gauthier's summary of the group. Nevertheless, complete though the work is, there are some few omissions; thus while a paper on the Mauritius Bryozoa, which is solely of zoological interest, is recorded and summarized, the Sarrasins' important work on the Echinothuridæ is not mentioned, though of especial interest to palæontologists. The list of abbreviations, which was quite inadequate in previous volumes, has disappeared entirely from the present, and one is left to guess what is meant by the G.F.F. and the Jahrbuch G.R.A.: the brevity in such cases strikes one as unnecessary in contrast to those in which such words as Rendiconti are printed in full. In many cases there is a lack of uniformity in the abbreviations, and the same work is quoted differently on the same page. Sometimes no reference is given to the place of publication of a paper, as in Sansoni's "Note di mineralogia italiana" (1855). The frequent absence of cross-references in the case of joint authorship is also unfortunate.

In spite of such slips and omissions, it must be admitted that the Annuaire Géologique Universel is the most complete and reliable guide to current geological and palæntological literature. J. W. G.

CORRESPONDENCE.

THE CAMBRIAN CONGLOMERATE OF ST. DAVIDS.

Sir,—The statement to which Dr. Hicks objects may be somewhat loosely worded, but if the words used be clearly defined it is not very far from the truth. In speaking of a conglomerate we distinguish "pebbles" and "matrix." When the word "fragment" is used, it is generally supposed to refer to the former; the latter, however, may also contain fragments of smaller size; and with the exception of certain true pebbles from Whitesand Bay and Ramsey Island, all the fragments referred to by Dr. Hicks come under this category. The conglomerate of Ramsey Island is truly "composed" of felsite pebbles, but there is no proof of its age. Elsewhere the conglomerates may *contain* fragments of various rocks, but they are mainly *composed* of quartz pebbles. My statement is a re-echo of the words of Prof. Hughes that "he did not believe that the little particles of felspathic rock in the grit would carry conviction." Indeed in any case it is very extraordinary that though the present beach at Chanter's Seat and elsewhere is strewn with large granite pebbles from the neighbourhood, the older conglomerate is so free from them, and so full of quartz from somewhere else. This fact, which thus stated can scarcely be denied, tends to minimize the interval between the conglomerate and the underlying rocks, and the presence of small fragments of similar rocks which are abundant in Precambrian areas does not do much in the contrary direction.

Sept. 20, 1890. J. F. Blake.

METRICAL *v.* IMPERIAL STANDARDS.

SIR,—It is to be regretted that the valuable space of the pages of the GEOL. MAG. are threatened by a discussion of the merits of different systems of weights and measures. The question has been threshed out in the "English Mechanic," photographic and other journals quite recently. As one of those who use metrical measurements in my communications to the three papers mentioned, would you kindly allow me to explain my own reasons, which are probably the same as those of the other culprits. As an Englishman, educated in England, I have the greatest respect for most of her institutions and systems; but I am not *Jingoist* enough (pardon the expression) to extend my patriotic feelings to the irrational system of your so-called Imperial Standards, which cost me many a caning and numerous other miseries during my school-days. When I took up my residence abroad, my mental conception of an inch and a foot was fairly good; but ells, furlongs, miles, gills, pints, gallons, pecks, bushels, grains, scruples, drachms, and many other barbarous units were always very hazy conceptions. My first initiation to metrical measurements was the picture of a decimetre in Roscoe's small chemistry book. I set myself to work for half an hour on two or three occasions, and soon gained a clear mental estimate of all metrical standards which years of patient labour and much practice had failed to give me of Imperial standards. The great point is that the measure of lengths, fluids, solids, with their relations to specific gravity, temperature, coinage, etc., can be calculated in a few seconds by an ordinary person, whilst the relationship of the Imperial standards requires lengthy intricate calculations on paper by a practised mind. So superior do I find the metrical system that I now convert the data of any problem from English to a metrical form, make my calculations, and reconvert the answer to English form.

The objections of the writer of the letter in last month's GEOL. MAG. are of the usual invalid kind. In the first place he seems to think one must be a French scholar to understand metrical measurements, whereas if any other than his own language is necessary, it is Greek and Latin, as all the names of the weights and measures are derived from them; but I would ask if the writer of the letter ever attempted to investigate the meanings of furlong, drachm, scruple, carat, and other incomprehensible and useless denominations of our Imperial standard units, whilst a most elementary knowledge is sufficient to explain a decimetre, a milligramme, or a hectolitre. The next error is to refer the use of the metrical system entirely to the French—true it originated in the minds of French philosophers and physicists, but it has long been very extensively adopted by other countries. All said about Englishmen and English journals is out of place, for the metrical system is recognized as legal Standards by Act of the British Imperial Parliament, and it is only our insular conservatism that makes us retain an old, cumbersome, and even dangerous system of Standards not much superior to those used from earliest historic times. If people wish to understand

scientific papers where the metrical system is used, it is to be inferred that they are capable of learning that system, which is not more difficult than the multiplication table of 10.

The prognostications of your correspondent I fear are of little value, for I find daily the metrical system is replacing more and more the barbarous standards. I know of some large English engineering works recently opened in Italy where all the English engineers, after a few months' absence from home, adopt the metrical system as far as the inch-calibred machinery will allow, and constantly grumble at the two-foot rule.

Lastly, allow me to state that once it was my practice to put old English equivalents by the side of the metrical measurements, but I dropped the practice because one Editor wrote to me saying that it was a presupposed fact that the readers of his journal understood the metrical system, and it might offend their dignity to be told the English equivalent of 2·5 centimetres, etc. Another Editor wrote that it was superfluous and added to the length of the paper.

Chemists and physicists have universally adopted the metrical system, mathematicians, astronomers, etc., prefer it, and I maintain that geologists—especially those who write for the future in the GEOL. MAG.—the least conservative of all scientists, should not be the last to give up an archaic if not an archean system.

NAPLES, *Oct. 14th*, 1890. H. J. JOHNSTON-LAVIS.

WIND WAVES AND TIDAL CURRENTS.

SIR,—Allow me to thank Mr. Stirrup for the invaluable information contained in his letter on "Wind Waves and Tidal Currents." It does not, however, affect the position taken up in my letter on "Tidal Action" as to the question of the action or inaction of *Tidal* currents on the floor of the English Channel. The Mediterranean being practically a tideless sea, the currents encountered by M. Fol could not possibly be Tidal, and herein lies the extreme value of the observations.

My investigation of wave-action was undertaken in order to prove the disturbing power of waves on the sea-bottom, and I proved my point up to the hilt, and indeed a little further, as the ascertained amount of disturbance exceeded what the theory of oscillating waves would allow.

In a paper submitted to the British Association in 1886, I pointed to the clean sand and shells in 100 fathoms and more at the mouth of the English Channel as evidence of the presence of wave-currents at a depth far below the reach of the heaviest oscillating waves, and said that "the presence of this deposit of clean sand and shells is at present unaccounted for, for there are no recognized agents competent to disturb and distribute such material below the depth of fifty fathoms:" at the same time I showed how a gale off Queenstown by the general disturbance of the water-level, stirred up seaweed in Torquay Harbour far beyond the radius of the atmospheric disturbance caused by the storm.

In a tidal sea it is impossible to isolate these far-reaching currents

from the ordinary tidal- and wave-currents, but now M. Fol in the tideless Mediterranean has done so, and what is of so much importance has clearly distinguished them from such wave- and tidal-currents. As already stated, M. Fol's currents cannot be tidal, but no more can they be attributed to ordinary storm waves, as Mr. Stirrup states that the disturbance is felt nearly as much at 30 metres as at 10 metres. This is also indicated by the character of the motion which is said to make the diver oscillate like a pendulum. An ordinary storm wave would impart more or less of a circular motion.

These wave-currents appear to originate in those swinging waves which, for lack of a better name, I have termed wind-pressure waves. They are moreover quite in their place in the Mediterranean, a sea which is subject to considerable changes of water-level from strong winds.

With respect to the English Channel, the tidal currents alone seem powerless to disturb the weakest organism, but occasional storms appear to hurl about gravel as though it were sand, and to give the fauna in general a decidedly bad time of it.

Mr. Stirrup's letter clears up the chief outstanding unexplained point in the problem of the action of waves and currents on the floor of the Channel, and I can only repeat my very sincere thanks for the same.

A. R. Hunt.

Southwood, Torquay.

MISCELLANEOUS.

Geological Survey of Ireland and the Royal College of Science.—We regret to learn that Professor Edward Hull, LL.D., F.R.S., severed his connexion upon the 30th September with the Geological Survey of Ireland, of which he has been Director for a period of nearly 21 years. He retires from the service consequently upon the completion of the one-inch Geological Survey of the country. Messrs. G. H. Kinahan, A. B. Wynne, R. J. Cruise, and W. F. Mitchell, have also retired from the service; Mr. Kinahan having served with distinction for a period of 36 years. A small staff has been retained, whose duty it is to keep the maps up to date, to give technical information to persons interested in mineral and similar developments, and to attend to the Survey collection now displayed in the new Science and Art Museum. Mr. J. Nolan (senior geologist) has been appointed chief of the local staff, and there remain with him Messrs. F. W. Egan, J. R. Kilroe, A. McHenry, Dr. J. S. Hyland, and Mr. R. Clarke (Fossil Collector). Professor Hull also resigns his position as Professor of Geology at the Royal College of Science, which he had held conjointly with the Directorship of the Survey. We have much pleasure in stating that Mr. G. A. J. Cole, F.G.S., who for several years has been assistant to Prof. Judd at the Normal School of Science, and has done much original work in Petrology, has been appointed to the vacant Professorship.